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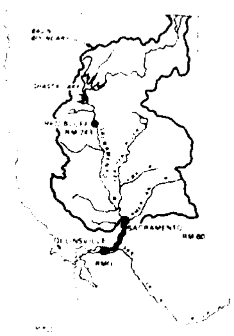

HYDRAULICS LABORATORY

(2)

TECHNICAL REPORT HL-90-19

A STUDY OF VEGETATION ON REVETMENTS SACRAMENTO RIVER BANK PROTECTION PROJECT

PHASE 1

LITERATURE REVIEW AND PILOT STUDY

by

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes methods and findings of the first phase (pilot study) of a 2-year study of the effect of volunteer woody vegetation on durability of Sacramento River revetments. The study consisted of a literature review, analysis of effects of woody vegetation on revetment performance during the 1986 flood using historical records and aerial photos, and visual inspection of revetments along the Sacramento River between river mile (RM) 84.5 and 119.

Federal and Corps of Engineers (CE) regulations specifically address removal of woody vegetation from levee slopes and flood control channels, but vegetation on revetted banks that are not part of a levee is not specifically prohibited. However, current CE maintenance standards as applied to the Sacramento River Flood Control Project prohibit

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Sacramento River
Streambank erosion
Streambank protection
Woody vegetation

19. ABSTRACT (Continued).

woody vegetation on revetments. Primary reasons that vegetation is undesirable on revetment include potential reduction of channel conveyance, impairment of revetment visibility for inspection, and reduced revetment durability. Only revetment durability was addressed in this study.

The literature review revealed little information regarding the effects of vegetation on revetment durability. The propensity of riverbank revetments to support woody vegetation and the habitat value of these plant communities were noted by several investigators. Although incorporation of plant materials in revetments is not standard engineering practice, several sources indicate that living woody vegetation growing through revetments adds strength. Accordingly, revetment designs that include planted or volunteer vegetation have been widely proposed and tested. Several CE field offices permit limited woody vegetation on revetments in particular projects.

Although the 1986 flood approached or exceeded record and design discharge magnitudes for much of the Sacramento River Bank Protection Project (SRBPP) reach of the Sacramento River (RM 0 to 194), documented revetment damage due to the flood was extremely limited. A review of Sacramento District files for emergency assistance requests revealed only six damaged sites. Study of aerial photographs, inspection records, and revetment construction dates showed that none of the damaged revetments supported significant woody vegetation at the time of the flood.

Five of the six revetment damage sites were located between RM 84.5 and 99.5; four of the five were riprap revetments on convex banks; and only one of the five was damaged severely enough to be repaired by 1989. Visual inspection of the banks of the Sacramento River from a boat in September 1989 (between the Fremont and Tisdale Weirs, RM 84.5 to 119) revealed additional (but slight) revetment damage, primarily to older cobble revetments. The observed damage appeared to be related to geotechnical factors or toe failure; revetment function did not seem to be impaired. Damage rates for revetments supporting woody vegetation tended to be lower than for revetments of the same age located on banks of similar curvature but without woody vegetation.

About 70 percent of the bank line of the inspected reach was revetted. About two thirds of the revetment was cobble, and about one third was rock riprap. Seven percent of the revetted bank line supported some type of woody vegetation.

Keywords: Banks waterways/protection; Channels waterways; Rivers/routing; Riprap/embankments/stability; Levees; Soil erosion; Flood control; Soil stabilization Vegetation/revetments.

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PREFACE

This report was prepared by the Environmental and Hydraulics Laboratories (EL and HL), US Army Engineer Waterways Experiment Station (WES), in fulfillment of Intra-Army Order for Reimbursable Services No. CESPK-ED-D-89-28. The study was conducted from March 1989 to June 1990. Messrs. Ed Sing and Jim Veres of the US Army Engineer District, Sacramento, served as points of contact. Dr. Bobby J. Brown, Chief, Hydraulic Analysis Branch (HAB), Hydraulic Structures Division (HSD), HL, WES, managed the project.

The report was prepared by Dr. F. Douglas Shields, Jr., and Mr. Loyde T. Ethridge of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, and Mr. Terry N. Waller, HAB, HL. Mr. Terry Taylor, contract student assigned to the WREG, provided assistance during the study. Technical assistance with regard to geomorphic issues was provided by Dr. M. D. Harvey, vice president of Water Engineering and Technology, Inc. Dr. C. V. Klimas of the EL and Dr. S. T. Maynord of the HL provided technical assistance with regard to the issues of tree coring and revetment performance, respectively. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

The work was accomplished under the direct supervision of Dr. John J. Ingram, Chief, WREG, and Dr. Bob Brown, Chief, HAB, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED; Dr. John Harrison, Chief, EL; Mr. Glenn A. Pickering, Chief, HSD, and Mr. Frank A. Herrmann, Jr., Chief, HL.

COL Larry B. Fulton, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.489	cubic meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
square feet	0.09290304	square meters
square miles	2.589998	square kilometers
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

A STUDY OF VEGETATION ON REVETMENTS

SACRAMENTO RIVER BANK PROTECTION PROJECT

PHASE 1: LITERATURE REVIEW AND PILOT STUDY

PART I: INTRODUCTION

Background

The Sacramento River Bank Protection Project (SRBPP), authorized in 1960, is currently under construction and consists of bank protection along the Sacramento River and its sloughs from Collinsville (river mile (RM) 0) to Chico Landing (RM 194), and along the lower Feather River, Bear River, Yolo Bypass, and Colusa Basin drainage canal. The SRBPP is authorized as a local cooperation project, and the US Army Corps of Engineers (CE) shares responsibility for the project with the State of California Reclamation Board. As of 1987 the project was about 90 percent complete. Bank protection works in the project reach of the Sacramento River are primarily quarry stone or river cobble revetments. Quarry stone is hereinafter referred to as riprap.

The SRBPP has been planned and constructed in phases, which are further subdivided into parts. During required coordination of the environmental studies for the Butte Basin Reach of the project (the upstream limits of the levee system to RM 194), the US Army Engineer District (USAED), Sacramento, provided a biological data report to the US Fish and Wildlife Service (USFWS) that identified the valley elderberry longhorn beetle (VELB) as a Federally listed endangered species in the project reach. The report stated that the project might adversely impact the VELB. Accordingly, the USFWS issued a Biological Opinion requiring that the Sacramento District implement several "reasonable and prudent alternatives" along with the project. One of these alternatives was that the CE conduct a 2-year study to determine the need for vegetation removal from banks protected by revetment. They further requested that emphasis be placed on sites where changes in shear stress and turbulence adjacent to the banks have occurred as a result of river morphology changes or the presence of the revetment. As part of the reasonable and prudent alternative, the CE was to prepare a new operation and maintenance manual for the Sacramento River Flood Control Project (SRFCP) that incorporated findings of the study. This report describes findings of the first phase (pilot study) of the required 2-year study.

Purpose

The purpose of this report is to present the methods developed and the results obtained during the pilot phase of the allowable vegetation study. This information will be used to decide whether to continue the study. If the study is to be continued, the recommendations presented in Part VII will be used as the basis for the scope, approach, and methods of the second phase.

Scope

This report contains a literature review, a description of a survey of files and records for documentation of revetment damage, and presentation of the pilot study approach, methods, and results. The literature review included both manual and electronic searches for references dealing with the effect of vegetation on revetment durability.

Since the 1986 flood was both large and recent, Sacramento District records were searched to identify Sacramento River revetments located between RM 0 and 194 damaged during the flood. Only six damaged sites were located, and five of the six sites were located between RM 84.5 and RM 99.5. Accordingly, the hydrologic reach* containing these five sites was selected for a pilot study of vegetation-damage association.

Semiannual inspection records and aerial photographs were carefully studied to determine the location and size of vegetation on all the known revetments in the pilot study reach at the time of the flood. Historic data from files and photographs were supplemented by two visual inspections of the pilot reach: the first by Harvey, Watson, and Schumm (1989) as part of a geomorphic study separate from this effort, in April 1989, and the second in September 1989. Data bases were constructed to contain a record for each 100 ft** of revetted bank line in the pilot reach. Data base fields included revetment material, construction date, and information about vegetation and

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* This reach extends from the Fremont Weir (RM 84.5) to the Tisdale Weir (RM 119). A description of the reach is provided in Part III.

** A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 7.

damage from various sources. Statistical and graphical techniques were used to investigate relationships among data base variables.

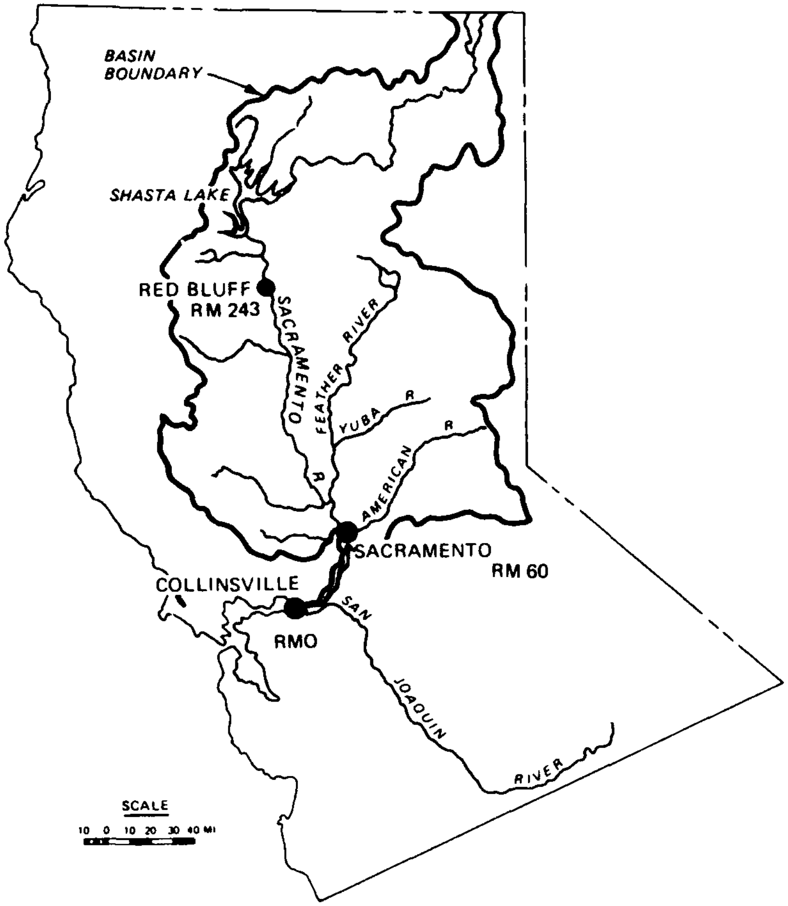
These procedures and results are presented in detail below, along with recommendations for the methods best suited for the proposed second phase of this effort. A synthesis of findings of the literature review and pilot study is also presented.

Study Area

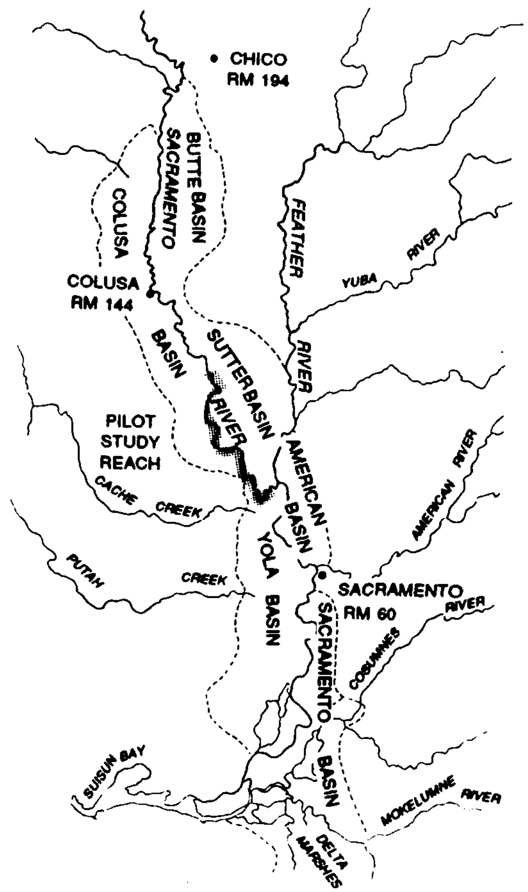
Sacramento River

The Sacramento River Basin occupies about 26,300 square miles in northern California, as shown in Figure 1. The basin is about 250 miles long and up to 140 miles wide and consists of a relatively flat valley about 50 miles wide flanked by abruptly rising mountain ranges. The Sacramento River is roughly 310 miles long, running from tributary creeks in the upper basin to Collinsville, where it joins the San Joaquin River and flows into Suisun Bay. Average discharge at Sacramento is about 25,000 cfs; average annual runoff is 18 million acre-feet. Flows are regulated by storage reservoirs located on the upper reaches of the Sacramento and major tributaries.

The character of the Sacramento River changes radically from headwaters to the mouth. From RM 194 (the upper limit of the Sacramento River Bank Protection Project) to RM 145 (Colusa), the river actively meanders between widely spaced levees. Levees are absent above RM 184 (west side) and RM 176 (east side). Gravel bars are found on convex points and midchannel, but gravel gradually grades to sand downstream. Between Colusa and RM 60 (Sacramento) the bed is fine sand, and banks are primarily composed of cohesive materials. Levees closely border the channel, usually separated from it by 50- to 100-ft berms. The channel has a meandering planform, but lateral migration is generally very slow relative to project time scale. Below Sacramento (RM 0-60), the river experiences tidal influence. This region is called the delta. Velocities even during floods are modest, and the primary erosion mechanism appears to be wave wash erosion due to wind- and boat-generated waves (Jones and Stokes Associates, Inc. 1987). A number of distributaries (sloughs) carry part of the flow. Both the river and the sloughs are very closely bordered by levees; in many reaches the levee water-side slope and the riverbank are one and the same.



a. Entire basin (after Henderson and Shields 1984)



b. Lower portion of basin containing Sacramento River Bank Protection Project (from Harvey 1989, after Gilbert 1917)

Figure 1. Sacramento River Basin

Sacramento River Flood Control Project

The SRFCP, authorized by the Flood Control Act of 1917, incorporated some of the levees and other structures built earlier, as described by Kelley (1989). Presently the SRFCP includes 977 miles of levees, overflow weirs, pumping plants and bypass channels along the Sacramento River and its sloughs from RM 0 to 194 and along lower reaches of several major tributaries. The system of bypass channels that is shown schematically in Figure 2 is based upon a natural system of overflow areas that predated the project. During floods, the bypass channels convey most of the discharge, and only a fraction of the flow remains in the river itself. The SRFCP provides protection to about 800,000 acres of agricultural and urban lands.

Sacramento River Bank Protection Project

Because so many of the SRFCP levees are very close to riverbanks that are eroding or have the potential to erode, bank protection has been necessary to ensure the integrity of the flood control system. In addition, stability of the river channel in the vicinity of the overflow weirs is essential to maintain the distribution of flood flows between the river and the bypasses so that the river channel capacity will not be exceeded. The Sacramento River Bank Protection Project was authorized to provide protection for the levees and flood control facilities of the SRFCP. Authorization for the SRBPP has occurred in phases as shown below:

Phase	Date	Authorized lin ft (miles)	Constructed lin ft (miles)
I	1960-1975	430,000 (81.4)	430,000 (81.4)
II	1974-1989	405,000 (76.7)	300,000 (56.7)
III	Under study		

The SRBPP has been implemented primarily by construction of continuous revetments along eroding banks. A comprehensive bank protection program has not been used; instead, revetments have been constructed to correct site-specific problems of levee erosion or to control channel migration where effective operation of the weirs might be jeopardized by migration. Most revetments constructed prior to about 1974 were built from river cobble; angular quarry stone riprap has been used for most revetments since then. Cobble revetments were typically placed on a 1V:3H slope, while rock has typically been placed on 1V:2.5H or 1V:2H. Most of the cobble revetments were

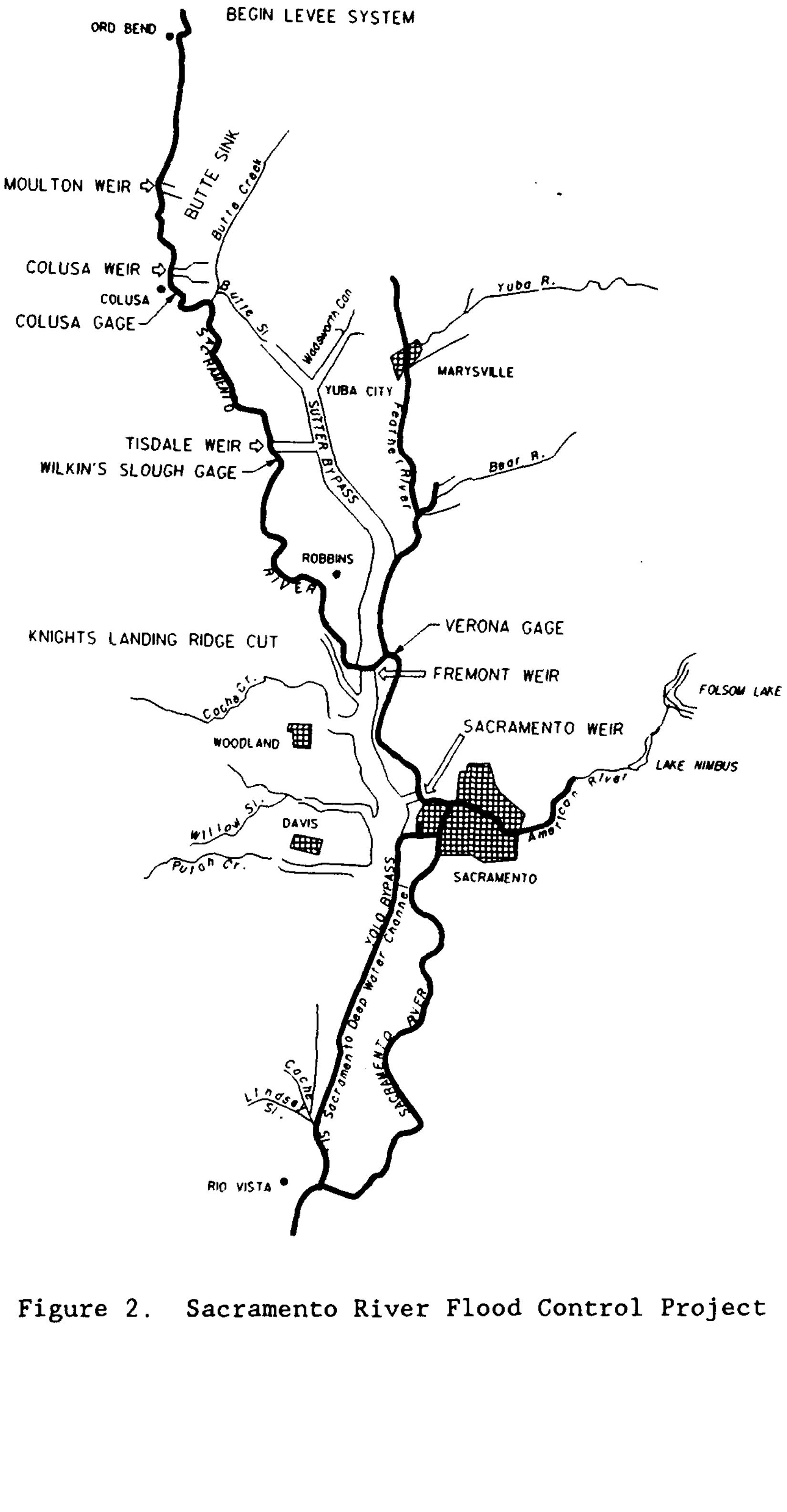


Figure 2. Sacramento River Flood Control Project

constructed with a blanket thickness of 12 in. above the low water* and 15 in. below low water. At the toe of the bank slope the revetment was extended an additional 10 ft to provide protection against toe scour. A rock toe wall (longitudinal toe dike) was used in locations where fill material was being used to raise the bank grade.

Newer rock riprap revetments have typical blanket thicknesses of 12 in. above low water and 18 in. below low water. Toe trenches are used with many of these revetments. Typical design details for Sacramento River revetments are shown in Figure 3.

About 99 of the 158 miles of SRBPP revetments are located on the Sacramento River itself; about 14 miles of these remain to be constructed. Of the total 158 miles of the SRBPP, 20 miles remain to be constructed. Ninety-six percent of the Sacramento River SRBPP revetments are below Colusa (RM 144); 40 percent are below Sacramento.

Many miles of revetment along the Sacramento River were not constructed as part of the SRBPP. These structures are the result of earlier Federal projects and private efforts. Jones and Stokes Associates, Inc. (1987) provide the following description of cumulative revetment length:

> Cumulative past and proposed SRBPP bank protection has been estimated to occupy 44 percent of the river banks in the lower reach (RM 0-60) below Sacramento, 39 percent of the banks between Sacramento and Colusa (RM 60-145), and 30 percent from Colusa to Chico Landing (RM 145-194). Many individual river miles are more than 50 percent occupied by SRBPP bank protection, particularly in RM 10-50 below Sacramento. When non-project riprap (i.e., by private interests or reclamation districts) is added, as much as 75 percent of the banks below Sacramento may be occupied by some form of bank protection.

Figure 4a shows the cumulative length of SRBPP revetments along the SRBPP reach of the Sacramento River as a function of time. Cumulative length was computed by summing the constructed or "project" length for each revetment. The actual length of revetted bank line is less than the project length because of overlap and replacement of failed areas. Figure 4b shows cumulative revetment length versus year of construction for all revetments (SRBPP) and all others) located between RM 78 and 177 as of 1987. Figures 4c and 4d present the cumulative revetment lengths as of 1989 plotted against river mile.

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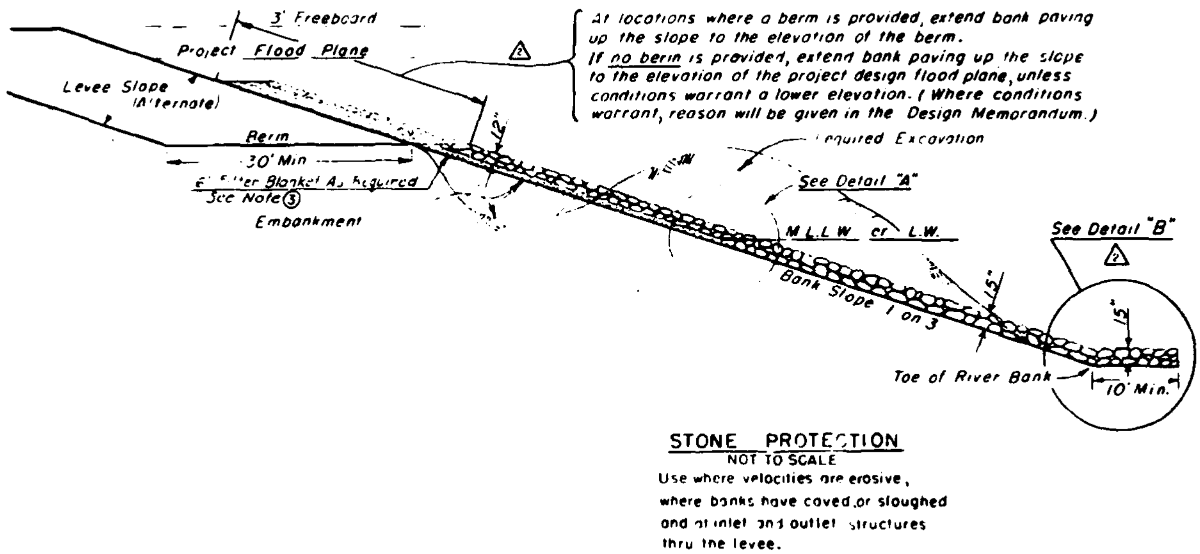
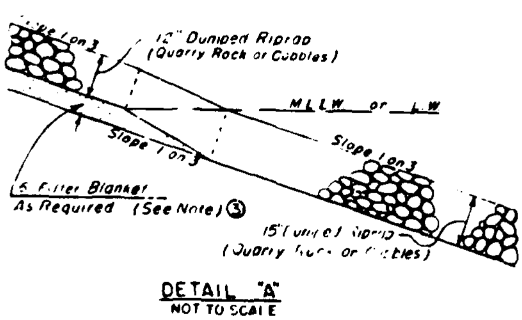
* The term low water refers to elevation shown as "M.L.L.W. or L.W." in Figure 3 and in the General Design Memorandum (USAED, Sacramento 1957).





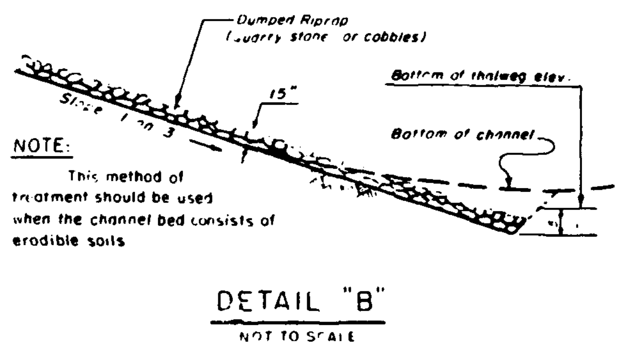


Figure 3. Typical Sacramento River revetment design details (from USAED, Sacramento 1957)

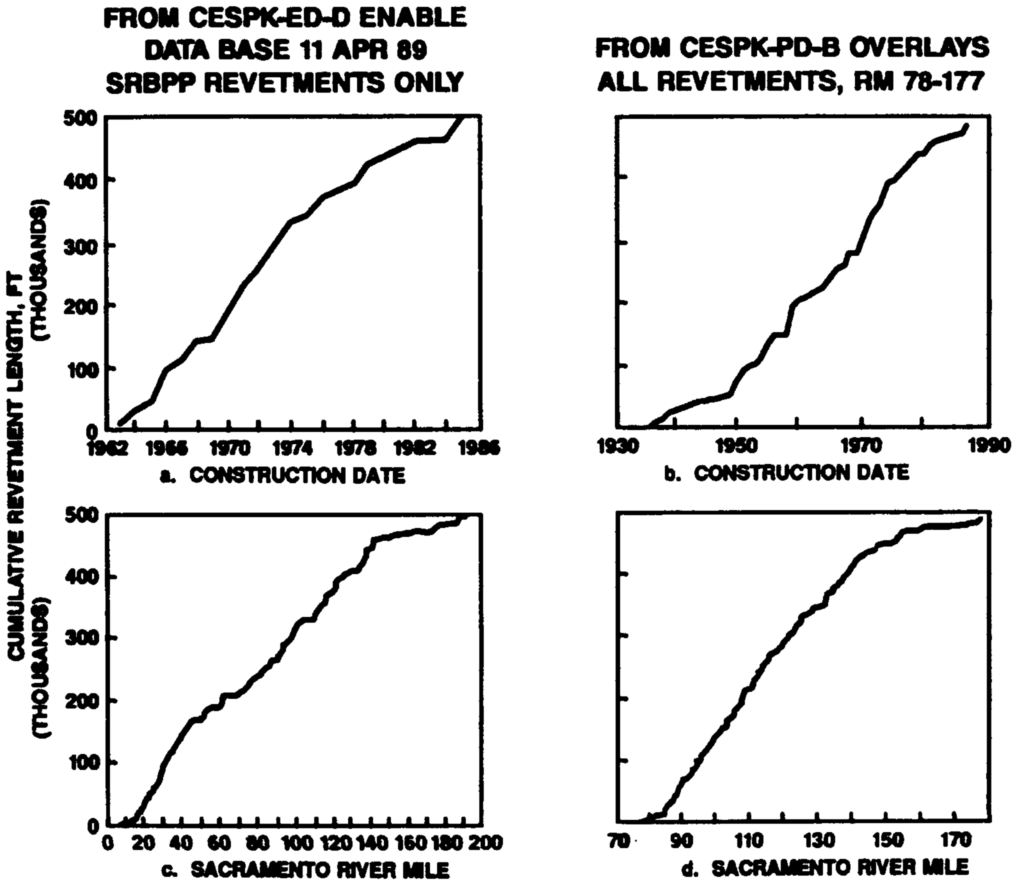


Figure 4. Cumulative revetment lengths versus construction date and river mile for all revetments and SRBPP revetments. "All revetments" includes those constructed by non-Federal interests and those constructed under pre-SRBPP authorities

Comparison of the curves in Figure 4 representing all revetments with those representing only SRBPP revetments shows that the latter comprise only about half of the revetments along the project reach of the Sacramento River. Both sets of curves show a total length of nearly 500,000 ft, but the curves for all revetments are for a reach only about half as long. However, the curve for all revetments includes some revetments that have been destroyed and/or replaced. Both curves show that the fraction of the bank line covered by revetment decreases sharply above Colusa.

Curves of cumulative revetment length versus construction date show that few revetments with known construction dates predate 1940. The SRBPP revetments are dated 1963 or later. The rate of construction has declined some since about 1978. The period of most rapid construction occurred in the late 1950s and early 1960s.

PART II: LITERATURE REVIEW

Methods for Literature Review

Manual search

A review of available literature on the effects of vegetation on riprap revetment and related issues was conducted. A manual search was first made using information on hand from previous related studies. The bibliographies from these documents were also searched. Most of the relevant literature was found in CE and California Department of Water Resources reports.

Dialog search

An electronic literature search was conducted using Dialog Information Services, Inc., on-line data bases. Key words were combined as shown in Figure 5, and the following data bases were searched:

NTIS 64-88/ISS09
COMPENDIX PLUS 70-88/MAR
BIOSIS PREVIEWS 69-88/APR
AGRICOLA 79-88/APR & 70-78/DEC
ISMEC: MECHANICAL ENGINEERING 73-88/JAN
OCEANIC ABSTRACTS 64-87/JAN
SCISEARCH 84-88, 78-80, 74-77, & 81-83
DISSERTATION ABSTRACTS ONLINE 1861-APR 88
ENVIRONLINE 70-88/MAR
POLLUTION ABSTRACTS 70-88/JAN
AQUATIC SCIENCE ABSTRACTS 78-88/JAN
CAB ABSTRACTS 84-88/JAN & 72-83
GEOARCHIVE 74-88/MAR
GEOREF 1785-1988/MAR
GEOBASE 80-MAR 88
SPIN 75-88/APR
TRIS 70-87/FEB
GPO MONTHLY CATALOG JUL 76 TO APR 88
ENVIRONMENTAL BIBLIOGRAPHY 74-88/FEB
CONFERENCE PAPERS INDEX 73-88/JAN
FLUIDEX 73/88 FEB
AQUACULTURE 70-84/JAN
WATER RESOURCES ABSTRACTS 68-88/APR

CURRENT TECHNOLOGY INDEX 81-88/FEB

SUPERTECH 73-88/MAR

WATERNET 71-88/MAR

SOVIET SCIENCE & TECHNOLOGY 75-86/JAN 88

LC MARC 79-88/FEB

BRITISH BOOKS IN PRINT MAR 88

BOOKS IN PRINT THRU 1988/MAR

WILEY CATALOG/ONLINE - JAN 88

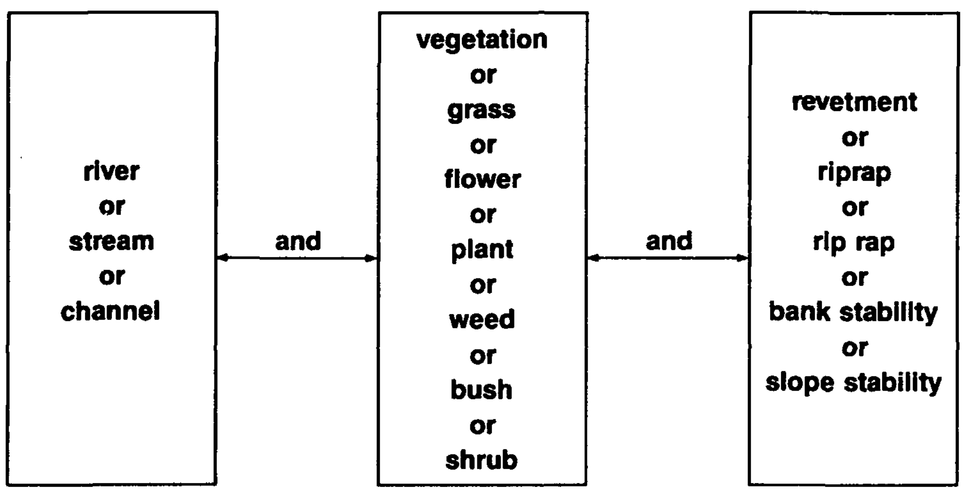


Figure 5. Keyword combinations used for electronic literature search

Roughly 327 hits were obtained using the search strategy shown in Figure 5. Many of these were duplicates, and only a small number of these documents were relevant to this study.

<u>Review</u>

Documents deemed to be relevant based on review of title and abstract were studied, and a one-page abstract was prepared for each document. Aspects germane to this study (i.e., effects of naturally occurring vegetation on riprap revetment durability) were emphasized. The one-page abstracts were then sorted according to the topics they treated, and an outline for a synthesis was composed. A draft synthesis was prepared and expanded as new sources of information came to light during the study.

Overview of Synthesis

A synthesis of the findings of the literature review is presented below. Three peripheral topics are briefly discussed first: environmental value of revetment vegetation, vegetation and streambank erosion, and intentional use of vegetation in revetments. Next, potential undesirable effects of revetment vegetation are identified, and current maintenance standards and practices that apply to revetment vegetation are reviewed, particularly for areas of the Sacramento River Bank Protection Project. The last section summarizes recent vegetation surveys along the Sacramento River and discusses the current status of Sacramento River revetment vegetation.

Environmental Value of Revetment Vegetation

Riparian vegetation

Riparian vegetation is an important component of terrestrial and aquatic riparian habitat. A study of nesting birds in the alluvial corridor of the River Garonne showed that the riparian woodlands are the richest and most densely populated woodlands because they provide an inland corridor for migrating birds (*Decamps*, *Joachim*, and Lauga 1987). A comparison of avian density and diversity found on naturally vegetated and riprap-covered banks along the Sacramento River showed that avian communities are heavily influenced in a positive manner by riparian vegetation (Henke and Stone 1978). This influence extended into adjacent agricultural areas up to 440 yd from the river.

Construction impacts

Revetment construction destroys riparian vegetation and prevents the use of the bank for nesting and denning. Over the long term, elimination of erosion by revetments halts the continuous process of floodplain habitat destruction and replacement. In portions of the floodplain that are not revetted or cleared, the successive vegetation stages of the riparian zone are replaced by climax vegetation. The diversity of habitat and animal species decreases. However, the population of individual species suited to the dominant vegetation habitat increases (Fletcher and Davidson 1988).

Revetment vegetation

After placement of riprap, natural vegetation from adjacent stands or from waterborne or windblown seeds usually invades sediment deposits in the bank protection materials or underlying soils (Figure 6). If vegetation is not removed by maintenance activities, a community of large trees may eventually develop, and biological effects of revetment construction will be reduced. Bank line habitat value for birds and other small wildlife species can be substantially improved by allowing vegetation to establish and remain on riprap. Dennis, Ellis, and Arnold (1981) pointed out the habitat value of brushy riprap in the Sacramento delta relative to unvegetated riprap. Brushy plant communities (blackberries, shrubby alders, stinging nettles, willows, wild radish, and smartweed) developed on riprapped banks not disturbed by maintenance for several years. Forbes et al. (1976) observed 2.6 times as many birds and 1.4 times as many bird species on revegetated revetments along the Willamette River as on recently cleared revetments. Jones and Stokes Associates, Inc. (1987) reported that adverse impacts of SRBPP revetment construction on juvenile salmon habitat could be partially addressed by planting woody vegetation in revetments.

Even though revetments occupy a relatively small acreage, the vegetation they support (if allowed to vegetate) is important and valuable. Riparian vegetation now occupies only 1 or 2 percent of the area it occupied in the Sacramento Basin in the 1850s, and much of this remaining area is affected by

Figure 6. Volunteer vegetation in riprap revetment, South Platte River below Chatfield Reservoir, near Denver, CO, September 1989

SRBPP activities (King 1984). Frayer, Peters, and Pywell (1989) found that California Central Valley freshwater wetland acreage (which includes riparian vegetation) decreased 43 percent between 1939 and the mid-1980s.

Vegetation and Streambank Erosion

A number of investigators have studied the relationship between erosion of unrevetted streambanks and naturally occurring vegetation. Some of this work is summarized below. When applying these findings to the problem at hand (effects of vegetation growing on revetment), it should be noted that vegetated natural banks often tend to be steeper than revetted banks. It stands to reason that the effect of woody vegetation growing on top of a steep, unprotected bank would be different than the effect of vegetation growing on a graded, low-angle revetted bank. Furthermore, effects would tend to be most divergent for steeper, higher natural banks.

Hey and Thorne (1986) obtained data from 62 stable gravel-bed river reaches in the United Kingdom with bankfull discharges ranging from about 250 to 16,000 cfs. Bank vegetation for each reach was classified into four categories based on the fraction of the bank line covered by trees and shrubs. Using regression, they determined that channels without trees or shrubs were roughly twice as wide as channels that had more than 50 percent of their bank lines covered by trees and shrubs.

Harvey, Watson and Schumm (1989) presented a literature review on vegetation and streambank erosion. Two investigations noted that the effect of vegetation on streambank erosion varies with the size of the river system (Zimmerman, Goodlett, and Comer 1967; Shifflett 1973). Studies conducted on small rivers have shown that riparian vegetation significantly reduced the rates of bank erosion (Smith 1976, Odgaard 1987), but those that studied larger rivers concluded that riparian vegetation had very little effect on bank erosion (Nanson and Hickin 1986). Conversely, Brice (1977) concluded that the Sacramento River was more sinuous and stable prior to the removal of riparian vegetation. Thompson (1957, as cited in Whitlow, Harris, and Leiser 1981) suggested that the natural levees in the Sacramento River delta prior to reclamation were "stabilized" by the presence of vegetation, but these levees are very different from concave banks upstream.

Harvey, Watson, and Schumm (1988a) conducted a geomorphic study of the Sacramento River between RM 174 and 194 and concluded that riparian vegetation has little or no effect on preventing erosion of unrevetted banks on the studied reach of the Sacramento River, disproving the earlier work by Brice (1977). Where substantial vegetation was observed along concave banks, it was always associated with abandoned channel fill deposits that consisted of clay material. These clay deposits were more resistant to erosion than the surrounding sediments, which consisted of unconsolidated sandy material. Evidently, vegetation was present because of the resistance of the underlying soils to erosion.

Use of Vegetation Within Bank Protection Structures

Because of perceived positive effects of vegetation on environmental resources and bank stability, vegetation is sometimes planted in or allowed to invade bank protection structures. Despite the fact that civil engineers often lack expertise in using plant materials to achieve engineering objectives (Bache and Coppin 1986), there are several examples of streambank protection methods that involve vegetation. Among these were CE projects in the US Army Engineer Districts, Portland, Mobile, Vicksburg, and Omaha. These projects are described in Part VI. In addition to the documents describing CE projects, references such as Schultze and Wilcox (1985), Schiechtl (1980), Gray and Leiser (1982), and the Pennsylvania Department of Environmental Resources (1986) describe planting woody vegetation such as willow stakes in riprap revetments to increase revetment strength. The Final Report of the Section 32 Program* (US Army Corps of Engineers (USACE) 1981) noted that, "If riprap is exposed to freshwater, vegetation will often grow through among the rocks, adding structural and aesthetic value to the bank." Jones and Stokes Associates, Inc. (1987) also noted that vegetation could potentially be used within riprap revetment to add strength.

The Department of Water Resources (DWR) performed a study on the Sacramento River in the mid-1960s in which four designs involving vegetation in revetment were tested (DWR 1967). Based on these four experiments, the DWR (1967) concluded that planting vegetation in revetment can be very expensive and difficult, but that the establishment of native vegetation in revetments

* Conducted by the CE under the authority of the Streambank Erosion Control Evaluation and Demonstration Act of 1974, this was a research and demonstration program addressing streambank erosion problems.

should be encouraged. Test sites were located at Garcia Bend, at the town of Hood, and near the town of Ryde. Results are summarized below and in Table 1.

Grasses and forbs

At the Garcia site, a section of berm was cleared of all vegetation, graded, and covered with cobble rock revetment in June 1963. One year later the revetment was covered with 6 in. of fill and planted with various types of grass. The vegetation prevented the fill from being washed away the following winter. The following spring, native vegetation began to grow into the test plots. A similar test was done at Hood on a section of existing rock riprap revetment. The revetment was covered with 12 in. of dredged material and seeded in the fall of 1964. During the winter of 1963-64, floodwaters completely destroyed the test site. The ground cover never had a chance to become established, and as a result, the fill material was completely washed away.

At the Ryde test site, a specially fabricated concrete block revetment was installed. The rectangular blocks had built-in openings to allow vegetation to grow through. The blocks were placed in a continuous mat from the top of the berm to a point below the low summer water level. Various species were planted into the voids to determine if they would grow in this tidal fluctuation zone. Shortly after the blocks were installed, certain portions of the mat were undermined by river currents, and the continuity of the mat was broken. The majority of the plantings failed to propagate through the voids, and the blocks were not fully effective in controlling erosion.

Trees

A test involving the placement of cobble stone around existing trees was also conducted at Garcia Bend. A section of berm area was selectively cleared (leaving several trees), graded, and revetted with 660 tons of 4-in. minimum cobble stone. Most of the rock was placed by hand because the existing trees prevented the use of equipment normally used for such work. The hand-placed revetment cost $1.51 per square foot, compared with $0.37 per square foot for normal rock placement. The history of the performance of this site is unknown.

Revetment Vegetation--Issues and Concerns

Although revetment vegetation can reduce adverse environmental impacts and possibly improve bank stability, there are several concerns with regard to

Table 1

Results of Experiments with Revetment Vegetation on the Sacramento River (DWR 1967)

Site	River Mile	Date of Test	Cost $	Test Section Length ft	Test Section Area sq ft	Test Section Slope ft/ft	Technique	Results
Garcia Bend	49	1964	9,388	300	12,500	1:2	Cobble revetment covered with soil and planted with grasses. Irrigated during first summer.	Remained in place the first year. Native plants began colonizing site.
Garcia Bend	49	--	2,510	200	8,600	1:1.5	Site selectively cleared and 4-in. minimum cobble hand-placed around trees.	Status unknown as of 1989. Construction costs 4 times higher due to hand labor requirements.
Hood	38	1964	9,537	400	6,200		Quarry rock revetment covered with 12-in. layer of dredged material and planted with grasses in fall.	Fill completely; washed away during December 1964.
Ryde	24	--	2,300		1,500	3:1	Continuous mat of 18- x 24- x 4-in. blocks with 3- x 6-in. voids. Voids planted.	Mattress destroyed by undermining. Plants failed to propagate in tidal zone.

undesirable effects. The main concerns involve the potential hazards of allowing native vegetation to invade and establish on revetments. Current maintenance standards are based on concerns for adverse effects of revetment vegetation or channel conveyance, revetment visibility for inspection, and revetment durability. Only durability is addressed herein. This study examines whether existing standards for revetment vegetation for the SRBPP (USAED, Sacramento 1955) can be modified without increasing the risk of revetment failure, and if so, what type and how much vegetation is allowable.

Potential effects of vegetation on durability involve several hypothetical mechanisms. For example, trees and shrubs growing in riprap may displace stones and create a weak spot in the revetment that could lead to failure (Riley 1981). Observations of many SRBPP revetments indicate that vegetation is growing on and within sediments that have accumulated on top of the revetments. The effect of this type of vegetation on revetment integrity is unknown. There is also concern that holes created when trees are uprooted by forces of wind or water (Figure 7) will lead to progressive failure (Riley 1981). It has also been suggested that flow around large stems and associated trapped debris could lead to local scour of riprap.

Maintenance Standards for Revetment Vegetation

Maintenance guidelines for CE flood control projects are generated under the authority of Code of Federal Regulations, Title 33, Section 208.10 (CFR, Title 33), as shown in Table 2. CFR, Title 33, does not clearly prohibit woody vegetation on revetments. There are, however, subsections that address removal of vegetation from levees, floodwalls, drainage structures, closure structures, pumping plants, channels and floodways, and miscellaneous facilities. Certain portions of subsections dealing with levees, channels, and floodways may indirectly require maintenance of revetments to allow for inspection, prevent floodway obstruction, and prevent displacement of riprap. The subsection on levees requires routine mowing of grass and weeds and the removal of wild growth. The subsections on channels and floodways require that the channel be kept clear of debris, weeds, and wild growth.

The Sacramento District has provided operation and maintenance (O&M) manuals for each major unit of the Sacramento River Flood Control Project to the State and to local interests, in accordance with CFR, Title 33, Section 208.10. Sections of these manuals dealing with maintenance of vegetation on

Figure 7. Large cottonwood uprooted from cobble revetment by wind, near Sacramento River, February 1989

revetment are based on a standard O&M manual (USAED, Sacramento 1955). The standard manual is based on CE regulations (Engineer Regulations (ERs) 1130-2-339 and 1130-2-303) and CFR, Title 33, Section 208.10 (Table 2). The USAED, Sacramento (1955), does not clearly prohibit woody vegetation on revetments.

The SRBPP has been granted a waiver of the provision of Title 33 that requires routine mowing and development of sod because climate conditions do not allow sod-forming grass to grow without irrigation. Title 33 also directs that measures be taken to retard bank erosion by planting willows or other suitable growth on areas riverward of levees. ER 1130-2-339 contains a separate section on maintenance of revetted areas that requires that these areas be kept clear of undesirable growth, yet "undesirable growth" is not defined in the regulation. There is also a section on control of wild growth that requires clearing of "undesirable wild growth" and "brush cover or other growth that interferes with inspection." Provisions for maintenance of channel and floodway vegetation and levee vegetation are nearly identical to the corresponding subsections of Title 33, Section 208.10. ER 1130-2-303 (Appendix I, paragraph 5.11) deals with inspection of bank protection for displaced stone but does not mention vegetation.

Table 2

Chain of Authority Regarding Removal of Vegetation from Revetments

Level	Controlling Document	Typical Language
National	CFR, Title 33, Sec. 208.10, 9 Aug 1944, in accordance with authorities contained in Sec. 3 of the Flood Control Act of 22 Jun 1936 (49 Stat. 1571), as amended.	Requires that the channel or floodway be kept clear of debris, weeds, and wild growth and that riprap sections and deflection dikes and walls are in good condition.
Federal agency (CE)	ER 1130-2-339, 29 Oct 1973, "Inspection of Local Flood Protection Projects"	Requires that revetted areas be kept clear of undesirable growth and other growth that interferes with inspection.
	ER 1130-2-303, 15 Dec 1967, "Maintenance Guide"	Requires annual visual inspection for revetment damage or disarranged stone but does not mention vegetation.
	ER 1130-2-335, 5 Dec 1968, "Levee Maintenance Standards and Procedures"	Requires that levee embankment be kept free of brush, trees, and other undesirable wild growth. Levee slope protection to be maintained in good state of repair.
Specific CE project (SRFCP)	Standard O&M Manual, May 1955	Based on ERs 1130-2-339 and 1130-2-303
State agency (Reclamation Board and DWR)	Guide for Vegetation on Project Levees, 1 Dec 1967, revised 5 Sep 1969, 10 May 1974, 10 Dec 1976, 18 Dec 1981, and Interim Guide, July 1988	Vegetation is allowed within revetments, berms, and levee slopes unless it becomes a threat to the integrity of the revetment or flood control system.
Local interest	Implements policy from higher authorities; inspect revetment and levees twice a year.	Vegetation shall be thinned, pruned, topped, removed, or stabilized to correct any unsafe condition.

The authorized purpose of revetments on the Sacramento River is to protect the levee system and other key components of the SRFCP. In some locations the revetments and levees are so closely related in function and proximity that confusion exists regarding the issues of allowable vegetation on each structure type.* Although the same agencies are responsible for inspection and maintenance of levees and revetments, Federal and state documents contain different standards for levee and revetment vegetation. Standards for levee vegetation are more stringent because of the possibility of seepage and piping caused by plant roots. When revetment is constructed on the water-side slope of a levee, and the revetment is above the elevation of the land-side floodplain, the more stringent standards usually apply to both the revetment and the levee.

Carter and Anderson (1981) reviewed CE and DWR guidelines for allowable vegetation on central California levees and revetments and discussed some of the issues concerning constraints on vegetation. They concluded that more vegetation could be retained on and adjacent to flood control levees if the levee sections were enlarged to provide a zone for roots that is outside the basic structure required for flood control and if the levee and vegetation were properly maintained.

In 1981 the Reclamation Board unilaterally adopted a revised maintenance guide for allowable vegetation on SRFCP structures for use by local interests. The proposed guidelines allowed trees and shrubs on revetments on either levees or berms when the distance from the design freeboard elevation on the landward levee shoulder to the top of the revetment was 150 ft or greater. For relatively straight channels with velocities of 5 fps or less, the distance from the landward shoulder to the top of the revetment could be as little as 75 ft.

In 1987, and again in 1988, the Reclamation Board issued a subsequent version of the maintenance guidelines entitled "Draft Guide to Vegetation on Project Levees." This draft guide was more lenient and more specific as to species and sizes of allowable vegetation than the CE standards. The 1988 version directed that

> Vegetation may be allowed within revetments on banks or levee slopes unless or until, in the judgment of maintaining or

* There must be no confusion, however, regarding the scope of this report. This study deals exclusively with revetments. Issues associated with levee vegetation are not addressed.

inspection agencies, it has become a threat to the integrity of the revetment or in some other way threatens the integrity of the flood control system. Vegetation shall be thinned, pruned, topped, removed, or stabilized in such a way as to correct any unsafe condition.

The DWR requested approval of the 1988 Draft Guide from the CE. Negotiations between the CE and DWR are in progress regarding the content of the 1988 Draft Guide.

Sacramento River Revetment Vegetation

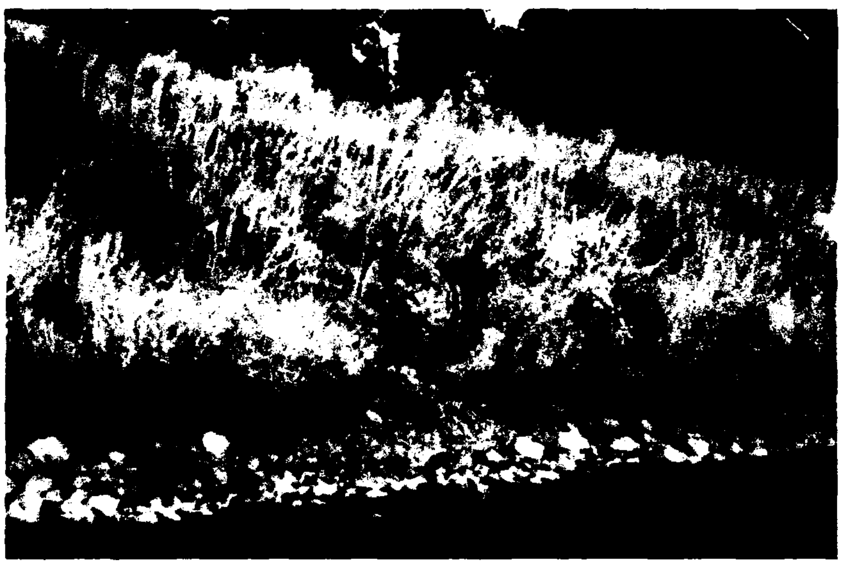
Visual inspection of revetments in the SRBPP reach reveals a wide range of maintenance levels and corresponding vegetation sizes and densities (DWR 1967, Riley 1981). Figure 8 depicts typical conditions observed at several locations in September 1989. The presence of vegetation on Sacramento River revetments is apparently controlled by maintenance practices (Harvey, Watson, and Schumm 1989), and compliance with CE standards varies greatly along the river.

Harvey, Watson, and Schumm (1989) observed vegetation growing through riprap on many of the revetted bends of the Sacramento River reach between RM 174 and 194. Deposition of sand in the riprap appeared to be a requirement for vegetation growth. The older riprap contained the most dense growth and formed a well-defined horizontal line. Hupp and Osterkamp (1985) suggested that the elevation of such a line is related to specific flow conditions.

Harvey, Watson, and Schumm (1989) also inspected the Sacramento River between RM 78 and 178 and for this reach concluded that sediment deposition in the riprap was not required for vegetation growth. However, riparian woody species flourished on riprap that was buried by laterally accreted sediment berms. Harvey, Watson, and Schumm (1989) suggested that relaxation of revetment maintenance standards would allow a large portion of the riparian habitat destroyed by revetment construction to be regained, as shown in Figure 9. On banks graded to 1V:2H, approximately 87 percent of the area removed from top bank would be available on the revetment, but sediment deposition and vegetation growth would be minimal. On banks of 1V:3H, approximately 81 percent of the top bank area lost would be regained as riparian habitat; sediment deposition would be extensive, and riparian habitat quality might be greater.

Harvey, Watson, and Schumm (1989) also concluded that riprap failure on the Sacramento River appeared to be unrelated to the presence or absence of

a. Looking upstream from Sacramento River, RM 72.5R, August 1987. Recently constructed revetment in foreground, overgrown revetment in background



b. Sacramento River, RM 91.2R, September 1989. Rock riprap revetment overgrown by grasses and forbs (referred to as Type 1 vegetation in Part IV of text)

Figure 8. Typical revetment vegetation, Sacramento River (Continued)

c. Cobble revetment, Sacramento River, RM 104.6R, September 1989. Type 2 vegetation (see Part IV)

d. Riprap revetment, Sacramento River, RM 141.5R, September 1989. Type 3 vegetation (see Part IV)

Figure 8. (Concluded)

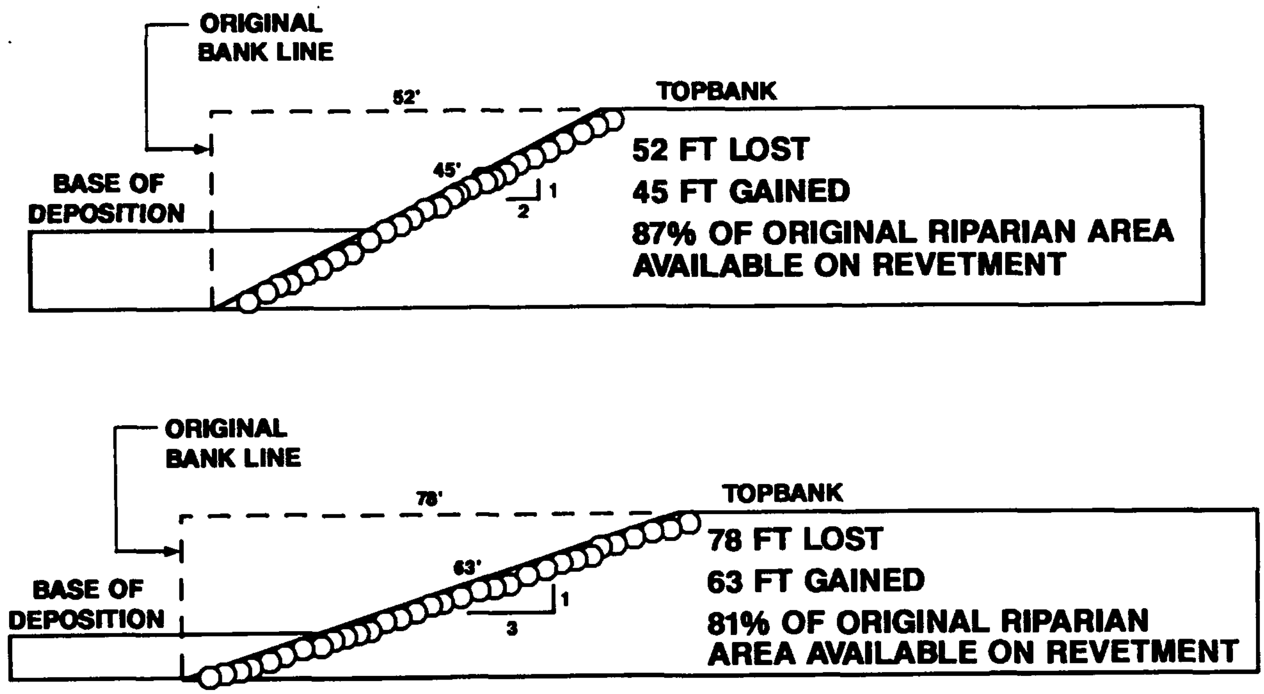


Figure 9. Potential for regaining lost riparian habitat by permitting vegetation on revetment (after Harvey, Watson, and Schumm 1989)

riparian vegetation. "Rock launching," movement of revetment due to slippage of underlying bank materials, was the primary mechanism of observed revetment failure.

Riley (1981) interviewed local and State maintenance and inspection staffs in the Sacramento River Flood Control Project area about the effects of vegetation on levees, including vegetation in levee revetments. Among those interviewed, vegetation in riprap was generally not considered to be a maintenance obstacle. Some reclamation districts and inspectors felt that removing vegetation from revetments could be wasteful and counterproductive. For example, farmers in Reclamation District 1600 felt that clearing vegetation from revetment was unnecessary and complained that this maintenance standard was one of their worst levee maintenance annoyances.

Several investigators have presented data regarding Sacramento River bank line or revetment vegetation, but their findings are not strictly compatible because they considered different reaches and their data were collected at different times. Nevertheless, these data do give a rough indication of the extent of vegetative cover on Sacramento River revetments. Accordingly, results of these studies are summarized below.

A considerable portion of the Sacramento River bank line and banks of other channels in the SRBPP supports woody vegetation. Jones and Stokes Associates, Inc. (1987), examined 1984 aerial photography of the Sacramento River between Collinsville and Sacramento (RM 0 to 59) for woody riparian vegetation. By assuming an average stand width of 30 ft, they computed that there were 191 acres of woody riparian vegetation in this reach, or about 3.2 acres/mile. If the area of woody riparian vegetation, 191 acres, is divided by the assumed stand width (30 ft) and the length of bank line (59 miles x 2), and if units are adjusted appropriately, it can be shown that approximately 44.5 percent of the bank line supported some type of woody vegetation. It should be noted that these figures do not distinguish between revetted and unprotected bank line. However, since Jones and Stokes Associates, Inc. (1987), estimated that perhaps 75 percent of the bank line in this reach is revetted, much of the revetment must support woody vegetation.

Jones and Stokes Associates, Inc. (1987), estimated that banks along the middle reach of the river (RM 60-145) supported an average of 22 acres of woody riparian vegetation per mile, and the upper reach (RM 145-194) supported an average of 125 acres per mile (Figure 10). The latter two reaches included tracts of vegetation that extend some distance from the channel. Similar, more detailed data for RM 60-243 were provided in Jones and Stokes Associates, Inc. (1985). These data are also shown in Figure 10.

The US Fish and Wildlife Service (USFWS) (1980) reported results of vegetation sampling on two revetments on the Sacramento River, one at Elkhorn (RM 72R) and the other near Knights Landing (RM 94R). About half the revetment at Elkhorn was covered with a band of sediment running parallel to the river. The revetment was heavily vegetated with early successional riparian species such as cottonwood, box elder, Oregon ash, and willow. At Knights Landing, sediments were deposited on the revetment and were overgrown with a well-developed herbaceous layer.

In the fall of 1986, 87 percent of the 1,054.7 miles of levees and bank protection in the Sacramento River and Tributaries Flood Control Project received either an outstanding or good maintenance rating, 9 percent received a fair rating, and 4 percent were rated poor (Snow 1987) (Figure 11a). Control of "wild growth" in revetments is necessary but not sufficient for a good rating. Maintenance that complied with or only slightly deviated from Federal and state requirements was rated outstanding or good; fair ratings indicated

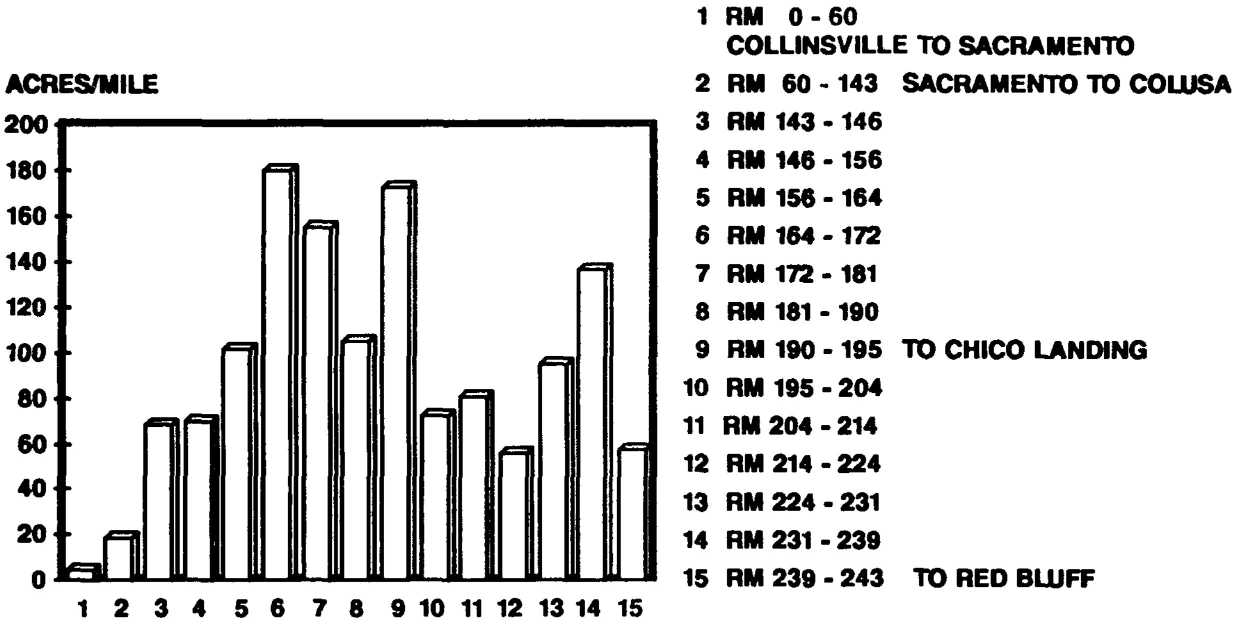


Figure 10. Woody riparian vegetation by reach, Sacramento River (data from Jones and Stokes Associates, Inc. 1985, 1987)

considerable departure from standards; and poor ratings indicated little to no maintenance or extensive deviation from standards.

Fall 1986 ratings for control of water-side wild growth (including revetments) on Sacramento River levees were 4 percent outstanding, 27 percent good, 25 percent fair, and 14 percent poor (Figure 11b) (Snow 1987). These figures are length percentages based on a total of 342.9 levee miles.

It was estimated* that less than 10 percent of the revetted area in the system is bare rock and soil and a similar amount is covered with trees 1 to 2 ft in diameter and 30 to 60 ft high. Many revetments are covered with sediment deposits and are overgrown with vines and low shrubs. Small woody vegetation less than 20 ft tall is the norm for most of the Sacramento River revetments.

In November 1987, each of the 390 Sacramento River revetments between RM 81.5 and RM 4.35 was categorized by DWR as complying with the CE vegetation standards, the proposed state vegetation standards, or "no maintenance" (DWR 1987). Forty-two percent (165 revetments) met CE standards, 23 percent

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* Personal Communication, 1987, Gene L. Snow, Department of Water Resources, Sacramento, CA.

(88 revetments met state standards, and 35 percent (137 revetments) were not receiving vegetation maintenance (Figure 11c). Revetments rated in the no maintenance category were between RM 81.5 and 62.6, RM 47.6 and 44.9, and RM 15.4 and 4.35. All revetments from RM 36.54 to 33.98 and from RM 32.88 to 28.1 met CE standards.

Riverine aquatic habitat shaded by overhanging riparian vegetation has been defined as Heavily Shaded Riverine Aquatic Hahitat (HSRAH). Dehaven and Weinrich (1988) mapped HSRAH along the lower Sacramento River from a boat. Mapping was accomplished for 64.3 miles of the lower Sacramento River between RM 14.6 and 78.9. Natural and revetted banks were also noted. About 27,600 lin ft of the revetted bank line provided HSRAH. If 75 percent of the bank line in this reach was revetted (Jones and Stokes Associates, Inc. 1987), then about 5.4 percent supported enough vegetation near the waterline to create HSRAH (Figure 11d). Footages shown in Figure 11 are widths of riparian plant canopy overhanging and shading the water at midday.

Effects of Maintenance on Plant Community

Dehaven and Michny (1987) described vegetation and habitat value at 152 revetments constructed as parts of Units 27-36 of the SRBPP, but no distinction was made among vegetation on the levee, berm, or revetment. Evidence was found that high-value habitat will regenerate after revetment construction. The number of sites where this occurred, however, appeared to he limited by maintenance practices of burning and disking.

The condition of vegetation on a revetment appears to be a function of both time elapsed since construction and maintenance or revetment repair. Using the line intercept method, Finn and Villa (1979) sampled vegetation on nine revetments upstream of the SRBPP in the reach between Chico Landing and Red Bluff. They found that species richness and the number of tree and shrub species were strongly correlated with the time elapsed since construction (Figure 12). Forbes et al. (1976) obtained similar results for plant communities growing six Willamette River CE revetments that had experienced varying periods of regrowth following maintenance. Bird and mammal use of these sites was also studied. Revetment clearing significantly impacted bird use, but differences in mammal use were not statistically significant.

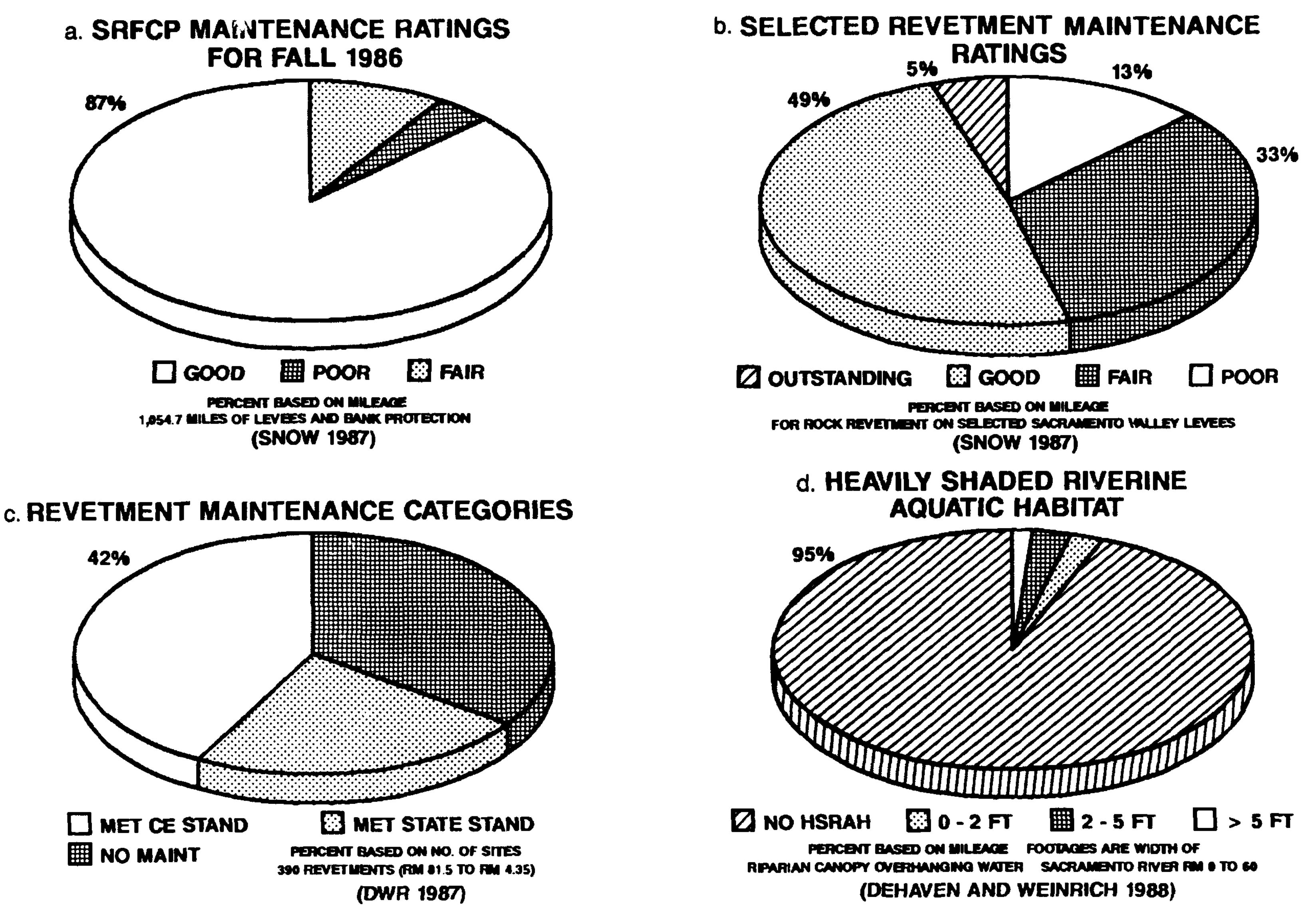

Figure 11. Indicators of the condition of Sacramento River revetment vegetation as reported by four sources

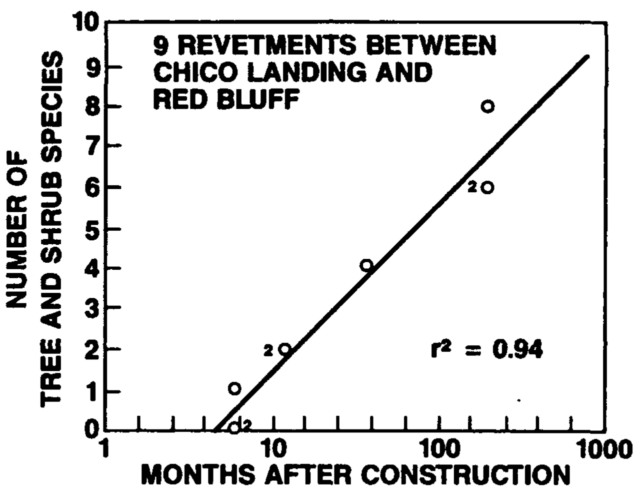

Figure 12. Number of woody species growing on revetment versus revetment age, Sacramento River (after Finn and Villa 1979). Five transects running perpendicular to river sampled at each revetted site

PART III: REVETMENT DAMAGE SURVEY

As noted above in Part II, objections to large vegetation on revetment fall into two main categories: inspectability and durability. This study is concerned with the effects of vegetation on durability. Two investigations of Sacramento River revetment durability were conducted. First, revetment durability during the 1986 flood was investigated by reviewing Sacramento District Public Law 84-99 (PL-99) Emergency Assistance Requests for the 1985-86 flood season. Second, the condition of revetments located within the Sacramento River reach between the Fremont and Tisdale Weirs (RM 84.5-119) was determined by visual inspection in September 1989. The inspection included mapping and sampling of woody vegetation growing on revetments. Data collected in September 1989 were compared to observations by Harvey, Watson, and Schumm (1989) made in April 1989.

February 1986 Flood

Revetment performance during the 1986 flood was of interest because of the great magnitude and low frequency of the event, and because the flood occurred fairly recently. Recency was important because it was felt that it would be easier to determine the nature and extent of revetment damage and preflood vegetation for a recent event.

Survey of Public Law 84-99 Files

Local interests may request emergency assistance from the CE in repairing flood control structures, and the CE may respond to such requests under the authority of PL-99. Files containing PL-99 requests received by the Sacramento District for damages during the 1985-86 flood season were examined in June 1988 and May 1989. All requests for Sacramento River sites were examined, including those outside the pilot study reach (RM 84.5-119). Sacramento District personnel believed that these requests contained documentation of all significant revetment damage resulting from the 1986 flood.* The files generally contained records of communications between the local

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* Personal Communications, 1988, Scott Morris and Jim Veres, USAED, Sacramento, Sacramento, CA.

interests and the Sacramento District as well as documentation of the District response, including inspection of the damaged sites. Of a total of 108 requests that were received, 31 were approved and 77 were denied. Seventeen of the 108 requests were for Sacramento River sites (Table 3); 7 of these were approved. Six of the seven approved requests were for sites in the SRBPP reach of the Sacramento River; one was located in the reach immediately upstream (Chico Landing to Red Bluff). Most of the PL-99 requests were for levee damages that did not involve revetments. Only two of the six approved requests for sites on the Sacramento River between RM 0 and 194 involved revetment damage.

Description of Pilot Study Reach

Review of the files (both approved and denied) listed in Table 3 revealed that only three requests involved damages to Sacramento River revetments in the SRBPP reach (Nos. 87, 88, and 103). Request 88 involved failure of a revetment at 187.1L constructed the year before the flood. Failure was possibly due to the fact that funding limitations prevented extension of the revetment far enough along the bank line.* Requests 87 and 103 involved a total of five sites, all located within a 15-mile-long reach. Details extracted from the PL-99 files regarding these five sites are summarized in Table 4.

Five of the six damaged revetment sites documented in PL-99 files were located between RM 84.5 and 99.5. The hydrologic reach containing these revetments is bounded by the Fremont Weir at RM 84.5 and the Tisdale Weir at RM 119. The RM 84.5-119 reach was therefore selected for more detailed investigation for this pilot effort (Figure 13). In addition to containing most of the documented 1986 flood damage, many of the revetments in this reach are partially covered with sediment deposits. The request by the USFWS for this study (mentioned in Part I) specifically mentioned situations leading to sediment covered revetments as a topic for investigation.

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* Personal Communication, 1988, Jim Veres, USAED, Sacramento, Sacramento, CA.

Table 3

1985-86 Sacramento District PL-99 Files for Sacramento River Sites

Request No.	Requester	County	Status	Remarks
7	R.D. 1600	Yolo	Approved	
9	M.A. #9	Sacramento	Approved	Pocket area
13	CA Rec. Bd. James Lewis	Butte	Denied	
22	R.D. 1000	Sacramento	Approved	Levee landside
38	Newhall Land & Farming Co.	Butte	Approved	Upstream of SRBPP reach
40	Peterson Ranch	Butte	Denied	Levee or bank failure - No bank protection
53	Bank of America	Tehama	Denied	RM 217
77	CA Dept. of Fish & Game, Reg. I	Shasta	Denied	
84	R.D. 150	Yolo	Denied	Levee erosion above revetted bank - No revetment problem
87	Sacramento River West Side Levee District	Yolo, Colusa	Denied	Project levee
88	DWR	Glenn, Sutter	Approved	
89	R.D. 827	Yolo	Approved	Project levee
93	Wm. H. Mitchell	Butte/Glenn	Denied	Levee at RM 195
100	CA Rec. Board	Sacramento	Denied	Levee failure
101	R.D. 3	Sacramento	Denied	Project levee
103	R.D. 1500	Sutter	Approved	
106	Tehama County & Smith Farms	Tehama	Denied	Project levee upper river, upstream of RM 200

Table 4

Review of 1986 PL-99 Files, Sacramento River Revetment Damage

Request Number	Location, RM	Material	Date of Construction	Length of Damage	Site Description from File
103	84.6L to 85.4L	Cobble	1944-1945	Entire length of revetment*	The levee is about 6 ft high and about 50 ft back from the edge of the berm; no rock toe was constructed; silty sand is now exposed; cobble at the toe is damaged and steep; the erosion occurred over a period of time.
103	92.6L	Rock	1979	40 ft	The site is on the inside of a bendway. Possibly a toe failure occurred and material slipped down (soil and rock). A 150-ft-long sand dune is downstream of the failure site.
103	94.0L	Rock	1985 (repair)	160 ft	The site is on the inside of a bendway. Riprap washed out and the berm was exposed. Up to 25 ft of bank line may have been lost. A sandbar has formed downstream. This site was repaired.
87	99.2R	Rock	1985	120 ft	Rock slipped off the slope. The revetment had a 1V:1H slope after failure.
103	99.5L	Rock	1979	140 ft	The site is on the inside of a bendway and had been repaired several times. Possibly a toe failure occurred and the bank material slipped down. The levee is about 200 ft from the river. A sandbar formed downstream. Twenty feet of bank line may have eroded.

* The file described the damage as being "along the entire length of the revetment" from 84.6 to 85.4L. Field inspections in April (Harvey, Watson, and Schumm 1989) and September 1989 found damage limited to 84.7 to 84.9L.

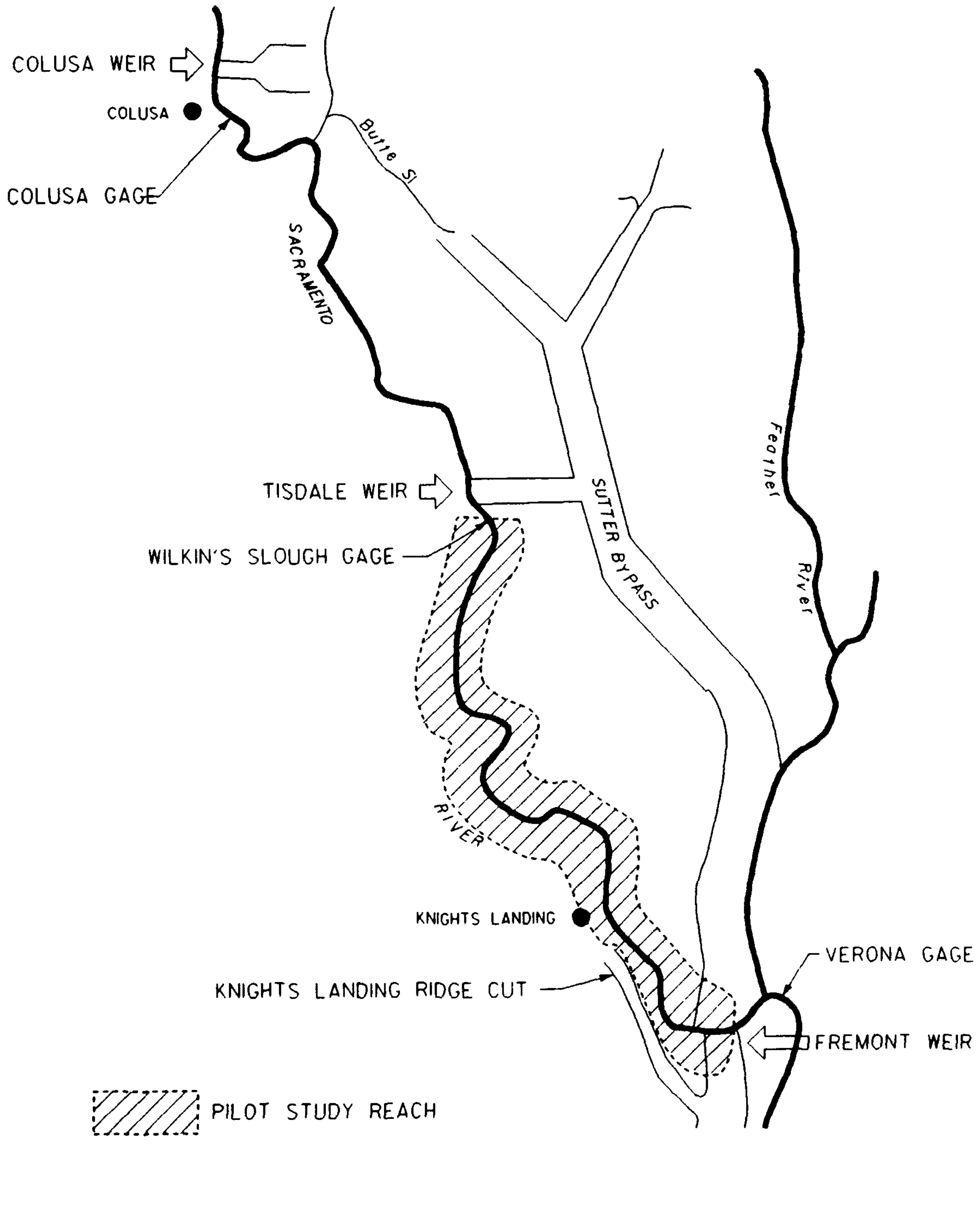

Figure 13. Pilot study reach

Geomorphology of Pilot Study Reach

Most of the material in this section is a review of Harvey, Watson, and Schumm (1989) with respect to the pilot study reach. The pilot reach is a fine-grained (sand) meandering channel that is relatively uniform with respect to most hydraulic and geomorphic parameters. During floods, there are no major inflows or outflows, and levees confine flood flows to the channel and a narrow overbank region. Although the Sacramento River is a meandering stream, in the pilot study reach about two-thirds of the bank line is revetted with cobble or rock riprap and, therefore, lateral migration is restricted. The pilot reach channel and the flood discharges it carries are smaller than upstream reaches because flood flows are diverted over weirs into bypasses and overflow basins. These overflow areas were present along the river prior to settlement and have been "formalized" by construction of weirs, levees, etc.

Human influence

The Sacramento River has been influenced by man as well as geologic controls. Four major factors have influenced the river since about 1840. The native riparian vegetation has been converted to agriculture use and urbanization. These land use changes have had a great effect on channel hydrology and sediment transport. The hydrology of the Sacramento River has changed due to dam construction. Shasta Dam, constructed at about Sacramento RM 310 in 1943, has reduced flood peaks but has increased the magnitude of more frequent discharges. Gravel mining on the upper Sacramento River has reduced the sediment supply in the pilot study reach. Hydraulic mining after 1850 increased the sediment supply in the Sacramento River above the pilot reach.

Sediments

The bed sediments in the pilot study reach were dominated by fine sand. Harvey, Watson, and Schumm (1989) presented D_{50} values for banks sampled at RM 87.6, 87.8, and 114.5 of 0.11, 0.12, and 0.13 mm, respectively. Eleven bank sediment samples taken between RM 87.6 and 114.5 had a mean sand content of 63.9 percent, with a standard deviation of 30.3 percent. Bed sediments were much coarser above Colusa.

Bank erosion mechanisms in the pilot reach were very dependent on bank sediments. Bank sediments included point bar deposits, abandoned channel fill, ancient meander belt deposits, and flood basin deposits. Harvey, Watson, and Schumm (1989) characterized the flood basin deposits as "silt and clay-rich, massive, impermeable, reduced sediments that contain preserved organic matter and manganese concentrations." At many locations in the pilot study reach flood basin deposits formed an erosion-resistant cohesive toe. In some cases seepage on the upper surface of this toe material led to rotational failures of the upper bank. Abandoned channel fills were composed of silts and clays that were resistant to erosion and locally affected bank erosion patterns. Ancient meander belt deposits such as the Modesto Formation also had a major effect on channel migration by resisting lateral erosion. Point bar deposits were composed of layers that have variable erosion rates.

Longitudinal berms of silt and clay sediments occurred on many of the revetted banks in the pilot reach, as shown in Figures 14 and 15. These wedge-shaped (in cross section) deposits were also found on unprotected banks and were extensive enough to represent a significant sediment storage location. The deposits generally had well-defined upper and lower boundaries, the elevations of which may be related to stages with specific durations. Harvey, Watson, and Schumm (1989) stated that specific gage, area, and velocity analyses suggested that these sediment deposits were gradually reducing low-flow channel conveyance. A similar effect on high-flow conveyance was not observed.

Sediment deposits were colonized by a wide range of vegetation, ranging from grass to very large trees such as old cottonwoods. The distribution of vegetation on the sediment deposits was apparently controlled by maintenance practices.

Channel morphology

Harvey, Watson, and Schumm (1989) divided the Sacramento River into subreaches by geomorphic characteristics. The subreaches in the pilot study reach are tabulated below.

Subreach	From (RM)	To (RM)	1986 Sinuosity	Geomorphic Type
3	84.5	87.0	1.29	I
4	87.0	88.5	1.88	II
5	88.5	95.5	1.37	I
6	95.5	107.5	2.34	II
7	107.5	118.5	1.29	I

Historical changes in planform, floodplain and channel slopes, and channel width and depth were evaluated. Sinuosity of some subreaches (4 and 6) has decreased over recorded history, but has actually changed very little since 1908.

Figure 14. Longitudinal sediment berm on revetment, Sacramento River, February 1989. Trees on opposite bank are growing on a sediment deposit on a revetment

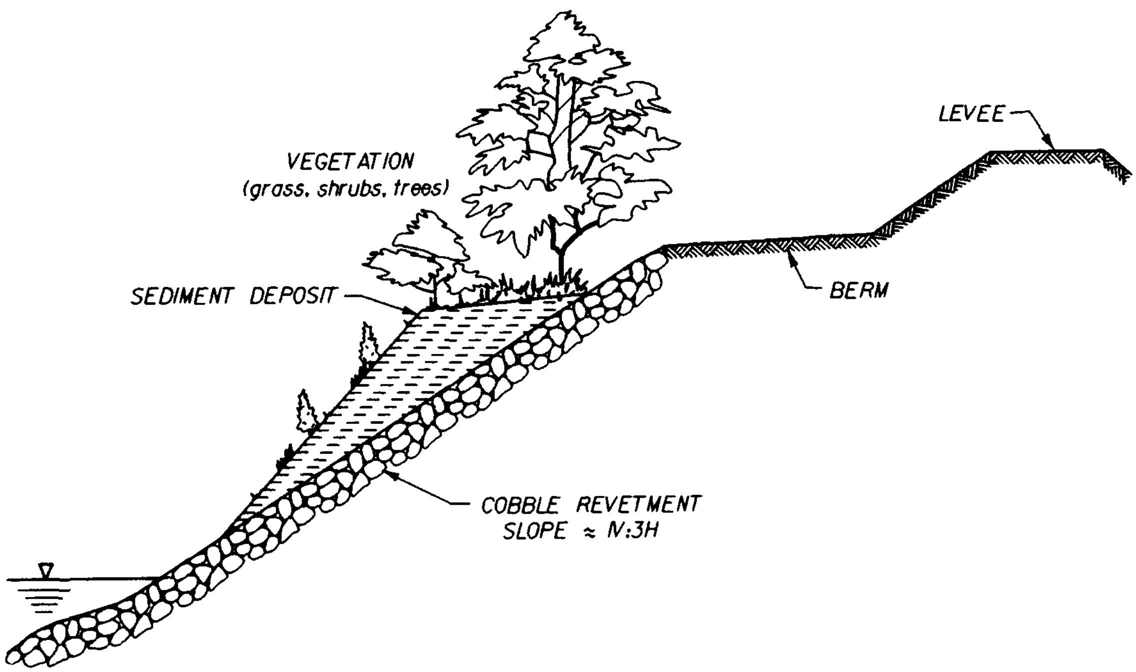

Figure 15. Cross section through a typical vegetated sediment deposit on a cobble revetment

The subreaches shown above were categorized by Harvey, Watson, and Schumm (1989) as Type I or II. The Type I subreaches were closely bordered by levees and were extensively revetted. Banks generally had cohesive toes; bed sediments were dominated by sand. Bank erosion was slow, channel planform was fixed, and progradational point bars were absent. Type II subreaches were characterized by setback levees that allowed channel migration. A cohesive toe was also generally present in Type II reaches, but middle and upper banks displayed a relatively diverse array of fluvial subenvironments. Bank stratigraphy included lithologically complex lateral accretion surfaces. Coarse sediments (gravel and cobble) were absent in both Type I and Type II reaches.

Channel bed profiles exist for 1909, 1938, and the 1970s. Approximate slope in the pilot reach was 0.0001. The 1938 thalweg profile was consistently lower than the 1909 profile. Sediment dredged from the channel was used for levees, and dredging was conducted to maintain a navigation channel into the 1970s. The 1970s data did not show additional degradation.

Channel area and the top width were fairly constant in the pilot study reach. Channel area ranged from about 5,000 to 10,000 sq ft, and top width from about 300 to 500 ft. Channel area and top width were smaller in the pilot study reach than for upstream reaches. Channel depth ranged from about 27 ft to 34 ft through the pilot reach, slightly greater than for upstream reaches.

Point bars were somewhat unusual in the pilot reach, and tend to be steep, high bars of sand and finer sediments. Flow separation around the points is evidenced by eddies, the location and size of which were stage dependent. Point bars that form at lower stages were eroded away at higher stages. On several revetted bendways, restriction of lateral channel migration has led to flow conditions that are causing accretion on the outside of the bend and erosion on the inside of the bend. Four of the five 1986 revetment damage sites in the pilot reach occur on the insides of bends.

In addition to high bars in bends, deposition of sand and silt onto channel margins was also observed. Harvey, Watson, and Schumm (1989) stated that these deposits affected channel roughness, bank slope, and vegetative colonization of revetted banks.

Hydrology and Hydraulics of Pilot Study Reach

Overflow basins and bypasses

The pilot study reach is flanked by natural overflow basins and bypasses (Figures 2 and 13). The Butte Basin lies to the northeast. Several of the eastern tributaries flow directly into this basin, and flood flows from the Sacramento River pass over weirs into this basin. Outflow from the Butte Basin flows into the Sutter Bypass, which lies directly east of the pilot study reach. Flows continue downstream into the Yolo Bypass. The Colusa Basin lies to the west of the pilot study reach. Colusa Basin was originally a natural Sacramento River overflow basin. However, flood control projects have altered the system so the Colusa Basin no longer carries Sacramento River overflows (USAED, Sacramento 1987).

The pilot study reach is located between the Tisdale and Fremont Weirs. The Tisdale Weir controls overflow from the Sacramento River to the Sutter Bypass. The Fremont Weir controls overflow into the Yolo Bypass. Design discharges for areas in the vicinity of the pilot reach are provided Table 5.

At the downstream end of the pilot reach, flows from the Sutter Bypass and Feather River enter the system, flow across the Fremont Weir, and down the Yolo Bypass. Discharges and stages on the lower end of the pilot study reach therefore reflect backwater effects from the Feather River and the Sutter Bypass.

High flows typically occur during the winter months of December through February. Flows of about 30,000 cfs or less entering the pilot reach pass through without overtopping the Tisdale Weir. Flows exceeding about 30,000 cfs are divided, with most of the discharge in excess of 30,000 cfs passing over the weir. Since the weir is ungated and since there are no hydraulic control structures in the river just downstream of the weir, the exact division of flow between the main channel and the weir is subject to many complex influences. Harvey, Watson, and Schumm (1989) presented an extensive discussion of many of these influences in their analyses of specific gage records.

Velocities

The design memorandum for Phase II of the SRBPP (USAED, Sacramento 1974) gives channel velocities for riprap design in the pilot reach. For flows at or below the project design flood flow, mean velocities range from 3.5 to 5 ft/sec, and maximum velocities range from 4.5 to 6.5 ft/sec (USAED,

Table 5

Sacramento River Flood Control Project Design Flows, cfs

Stream and Reach	SD 23*	Estimated as Constructed Capacity	Project Design Flows as Shown on File No.50-10-3334**
Sacramento River - Colusa Weir to Butte Slough Outfall	65,000	65,000	65,000
Butte Slough Outfall	7,000	1,000	1,000
Sacramento River - Butte Slough to Tisdale Weir	72,000	66,000	66,000
Tisdale Weir† and Bypass	38,500	38,000	38,000
Sacramento River - Tisdale Weir to Fremont Weir	33,500	30,000	30,000
Fremont Weir†	343,000	343,000	343,000
Sacramento River - Mouth Feather River to Sacramento Weir	107,000	107,000	107,000

* Senate Document No. 23, 69th Congress, 1st Session, 16 Dec 1925.
** Last revised August 1969.
† These weirs divert flows to bypass channels.

Sacramento 1974). Maximum measured point velocities in the pilot reach include the following (USAED, Sacramento 1957):

Location (RM)	Date	Discharge cfs	Maximum Velocity fps
106.7	19 Jan 56	27,000	4.18
104.3	19 Jan 56	27,000	3.00
89.6	28 Feb 56	23,900	4.38

A rough estimate of the mean velocity for the 1986 flood peak discharge (32,700 cfs, peak stage 49.50 ft NGVD) was calculated based on cross-sectional areas measured from two cross sections above and below the Wilkins Slough gage

(Harvey, Watson, and Schumm 1989). The cross-sectional areas below 50 NGVD were 8,170 and 7,380 sq ft, giving a mean area of 7,775 sq ft and a mean velocity of 4.2 fps.

1986 flood

February 1986 rainfall over northern California and northwestern Nevada is the storm of record. Rainfall in late January and early February brought rainfall levels to a normal level. Heavy rainfall began on 12 February, and rains continued in some areas until 22 February. The initial rains saturated the soil, and the majority of precipitation from the following storms became runoff.

Widespread flooding resulted from the storm. Flood control structures were strained throughout the Sacramento River Basin. Reservoir releases were coordinated to minimize downstream flows, but record discharges were recorded at many locations in the lower part of the system. The peak flow at Verona, just downstream of the pilot reach, surpassed the previous record. The peak flow at the latitude of Sacramento was 640,000 cfs, which exceeded the previous record of 475,000 cfs set in 1964. Flows in the Yolo Bypass of 532,000 cfs exceeded the design flow of 490,000 cfs. However, discharges in and near the pilot study reach were only slightly higher than the previous flood of record. The tabulation below shows 1986 peak, previous record, and design discharges for locations on the Sacramento River upstream of, within, and downstream of the pilot reach.

		Discharge, cfs		
Gage	River Mile	1986 Peak	Previous Maximum	Design Flow
Colusa	143.4	50,100	51,800	65,000
Wilkins Slough	117.6	32,700	32,300	30,000
Verona	79.0	92,900	80,900	107,000

The Wilkins Slough gage was the only gage in the pilot study reach in 1986. Since there are no inflows or outflows within the pilot study reach, discharges do not vary much through the reach. A discharge hydrograph for the flood event is shown in Figure 16. The gage water-surface elevation for the 32,700-cfs peak discharge was 49.50 ft NGVD. The project design flood elevation at RM 117.8 is at 52.6 ft, and the design levee grade elevation is 55.6 ft (USAED, Sacramento 1957). The 1986 flood peak was thus about 3 ft

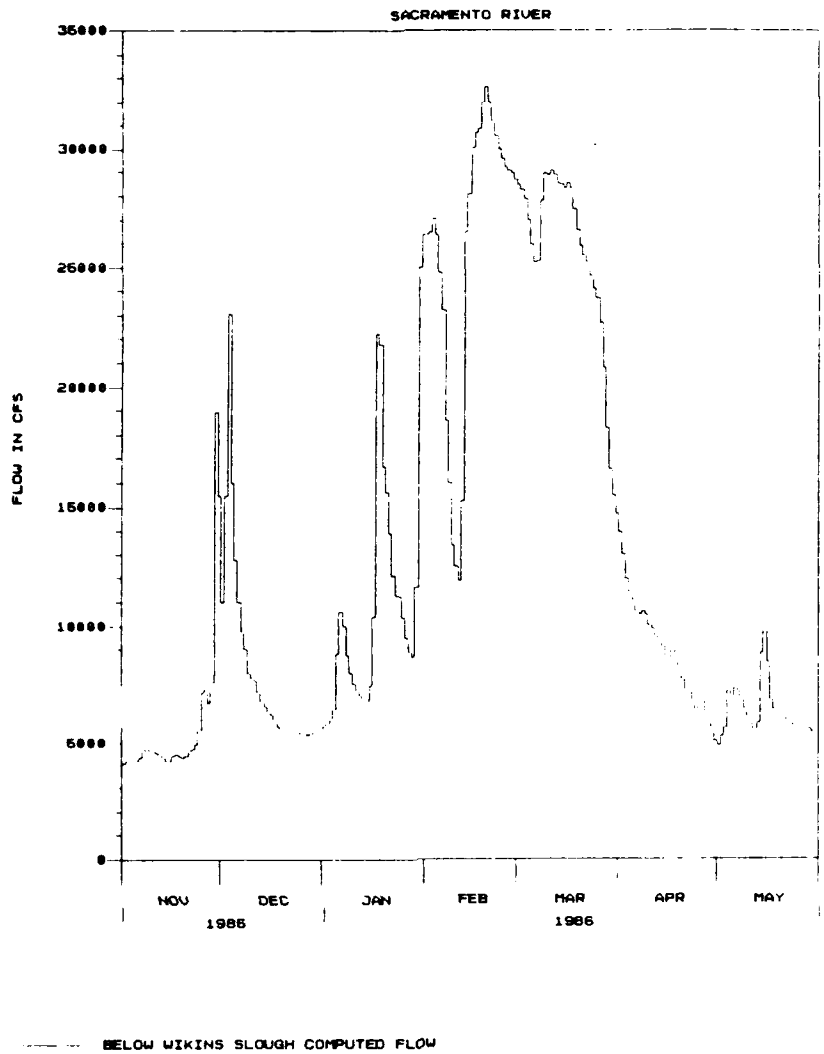

Figure 16. Discharge hydrograph, Sacramento River at Wilkins Slough (US Geological Survey data)

lower than the design water-surface profile, even though the design flow was exceeded.

The 1986 event was the flood of record in the pilot study reach. However, the 1986 discharge was not much greater than many other flows during the period of record because upstream weirs divert peak flows from the pilot study reach during flood events. Annual peak discharges for the period of record are shown in Figure 17. Discharges in both 1983 and 1984 exceeded 30,000 cfs, and discharges have exceeded 25,000 cfs in all but 4 years since 1954. Even though five of the six PL-99 requests concerning Sacramento River revetment damage were located in this reach, the 1986 flood event was not extraordinary with respect to previous discharges. Harvey, Watson, and

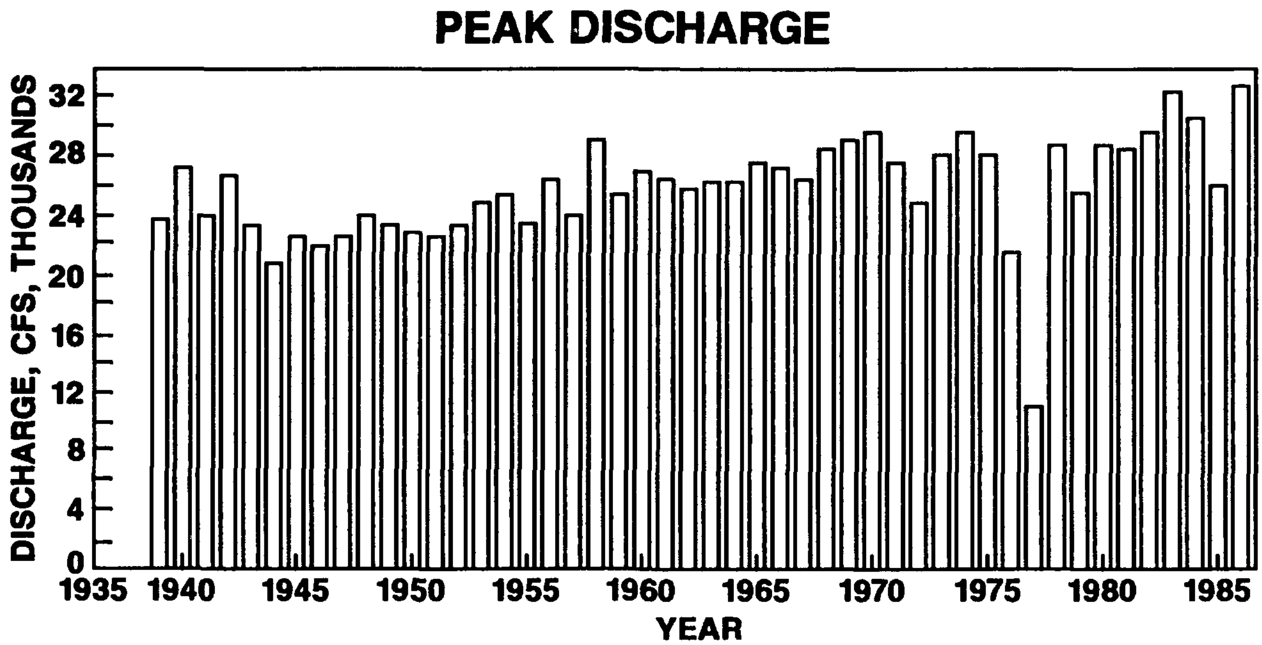

Figure 17. Annual peak discharges for pilot study reach, Sacramento River (after Harvey, Watson, and Schumm 1989)

Schumm (1989) indicated that peak discharges in this reach have been increasing. If this trend persists, a 30,000-cfs discharge may become more frequent.

Letter and Telephone Survey of Local Interests

Results of the survey of PL-99 requests were verified by soliciting information from local interests responsible for revetments in the pilot reach. These agencies were contacted by letter, followed by telephone calls. Locations of interests with revetments along the pilot reach are shown in Figure 18. A copy of the letter to these agencies, a list of addressees, and their responses are presented in Appendix A. Two reclamation districts (108 and 787) were contacted that have no maintenance responsibilities along the Sacramento River main channel. Questionnaires were returned by two of the remaining three addressees surveyed. Telephone conversations were conducted with all three.*

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* Personal Communications, Gordon Bailey, Manager, RD 1500; Kenneth E. Lerch, District Engineer, Sacramento River West Side Levee District; Levi Gurule, Assistant Director, Yolo County Service Area No. 6; and John M. Robertson, Director, Yolo County Service Area No. 6.

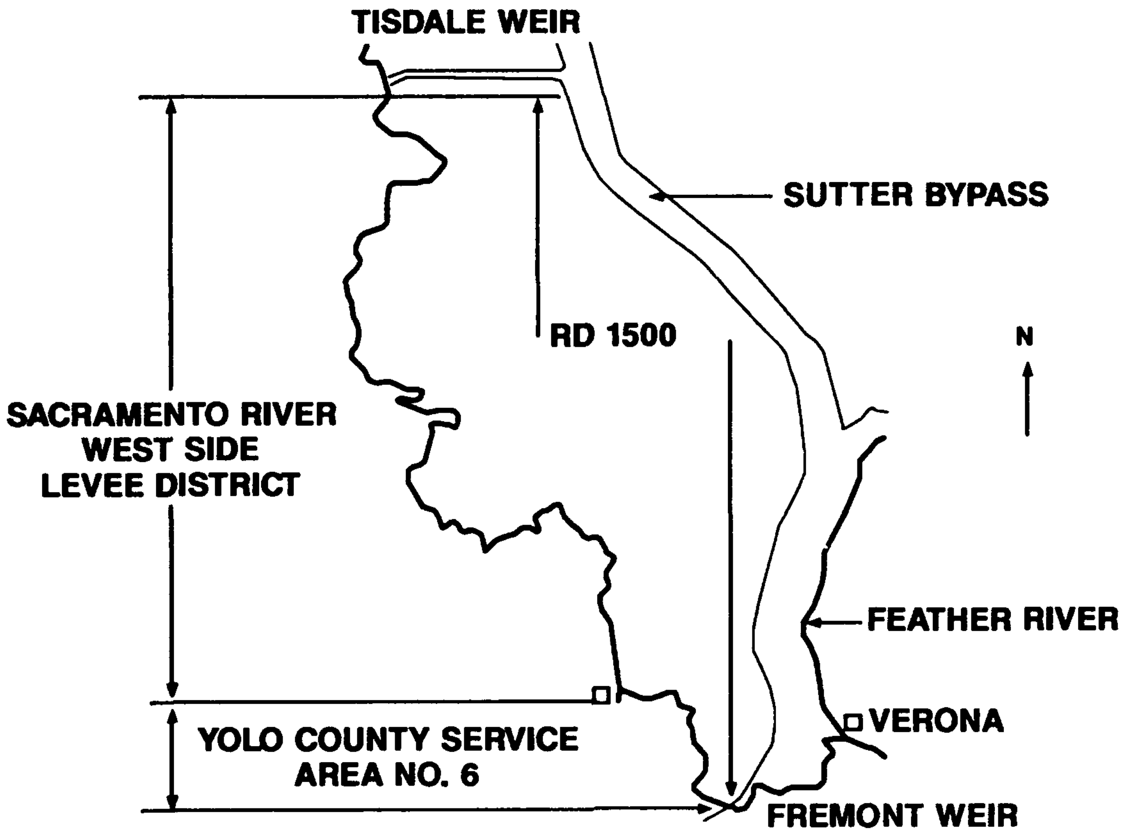

Figure 18. Locations of local interests responsible for maintaining revetments in the pilot study reach, Sacramento River

No additional 1986 flood damage sites were identified as a result of the letter and telephone survey. The questionnaire returned by RD 1500 confirmed 94.0L, and the Sacramento River West Side Levee District response confirmed 99.2R. The additional PL-99 sites (84.6 to 85.4L, 92.6L, and 99.5L) were confirmed by telephone. Only 94.0L was ever repaired.

Inspection of Pilot Study Reach

A field investigation of the pilot study reach was conducted on 25-27 September 1989. All of the revetments in the pilot study reach were inspected from the water. An additional reach near Colusa was inspected at the request of the Sacramento District since the reach was known to have large vegetation on some of the revetments. The PL-99 damage sites were visited, and revetment damage sites noted by Water Engineering and Technology, Inc. (WET), in April 1989 were also inspected. All damaged areas were noted on mapping sheets.

Revetment materials and vegetation types obtained from files and photographs were verified.

PL-99 sites

The five PL-99 1986 flood damage sites in the pilot study reach were inspected. The relative locations of these sites are shown in Figure 19. Photographs of each site from 1986 are shown as Figures 20a-e. Construction data and information from the PL-99 files are given in Tables 4 and 6. Of the five sites in the pilot study reach, only 94.0L was repaired after the 1986 flood. None of the sites supported large vegetation.

The damage at 92.6L, 94.0L, and 99.5L was on riprap revetments on convex sides of bends. The 84.6 to 85.4L site was an old cobble revetment (with some riprap at one end) where numerous small failures had occurred. Damage at 99.2R was on a recently constructed revetment.

Field inspection of the PL-99 sites revealed little additional information.

a. Although the toe at 84.6 to 85.4L was damaged at irregular intervals, the sediment deposits on the revetment were still in place, and none of the damage was severe enough to threaten the upper bank.*

b. Some rock downstream of the channel point at 92.6L was displaced. The rock surface was irregular did not appear to be in the as-constructed condition. However, there were no unprotected locations (exposed soil) above the water. Sand had covered the downstream portion of the revetment, so some damage could have been covered with sand.

c. The 94.0L revetment was repaired after the 1986 flood. The site had also been repaired in 1985 prior to the flood. The failure area was downstream of the point, however.

d. The 1986 flood damage at 99.5L was not repaired. A large sandbar covered the bank in the vicinity of the revetment damage, and the exact damage location could not be determined.

e. At 99.2R the upper limit of a slip failure was still visible in the rock as a semicircular arc. The damage was probably related to toe failure. Low herbaceous vegetation covered part of the revetment away from the damaged area.

General observations

Very few of the inspected revetments in the pilot study reach or in the reach near Colusa had any damage. Except for areas noted in the PL-99

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* See footnote to Table 4.

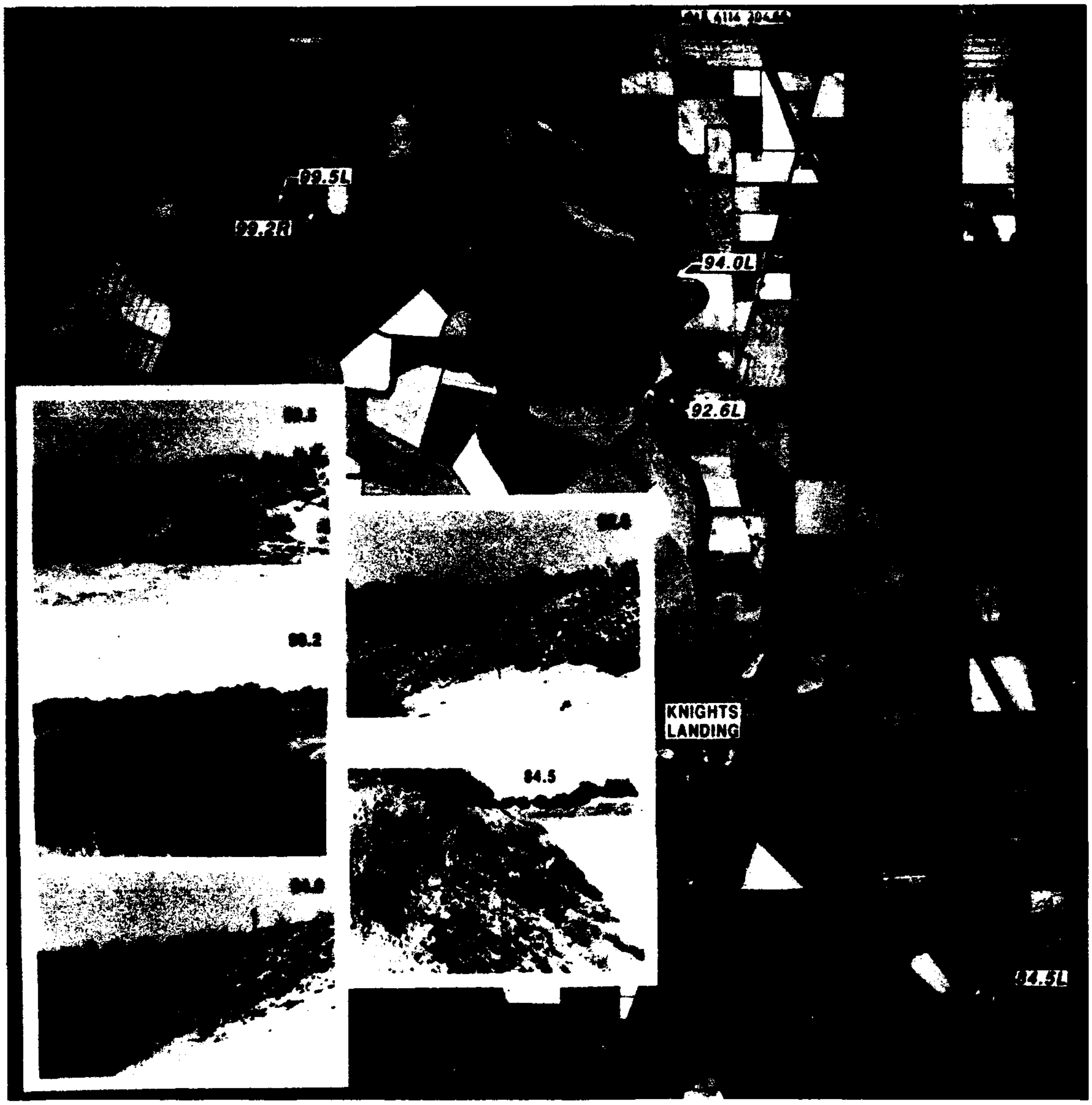
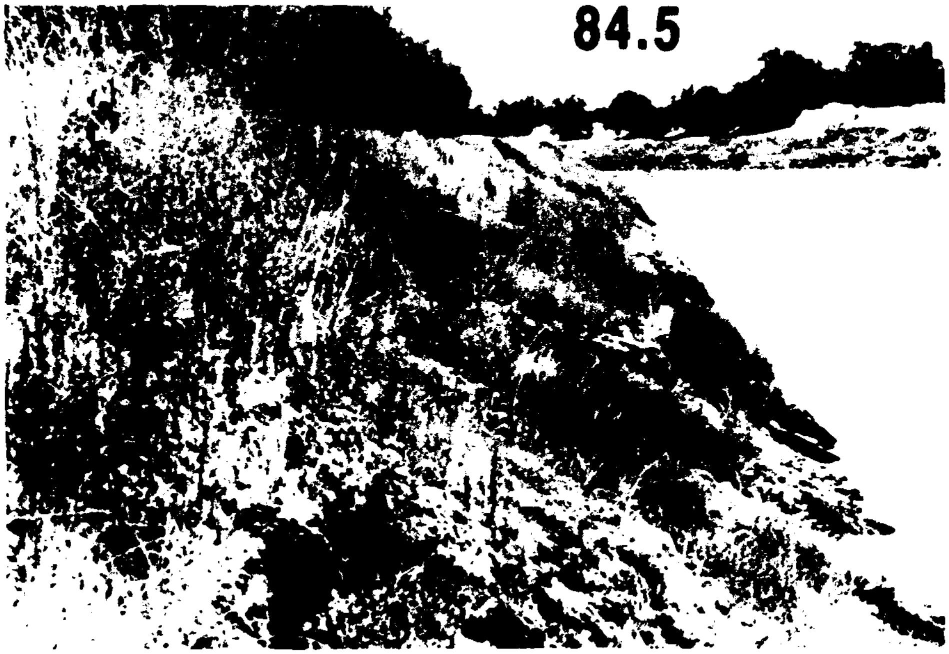


Figure 19. Location of 1986 flood PL-99 damage sites, pilot study reach, Sacramento River

requests, the observed damage tended to be short segments of toe damage grouped closely together. However, these groups of damaged areas tended to be isolated from each other. A cohesive toe was present at most of the damage sites. None of the toe damage that was observed appeared to be an immediate threat to the overall integrity of the revetment, the upper bank, or the levee. Almost all of the damaged sites not described in the PL-99 requests occurred on older, cobble revetments.

Most of the cobble revetments were covered with wedge-shaped sediment deposits as shown in Figure 15. The faces of the wedges extended from near



a. RM 84.6 to 85.4L

b. RM 92.6L

Figure 20. PL-99 damage sites, pilot study reach (Sheet 1 of 3)

c. RM 94.0L

d. RM 99.2R

Figure 20. (Sheet 2 of 3)

e. RM 99.5L

Figure 20. (Sheet 3 of 3)

Table 6

Construction Data for 1986 PL-99 Sites

Site, RM	Length ft	Year of Construction	Side Slope Vertical: Horizontal	Revetment Thickness, in. Above Water	Below Water	Elevation Rock Toe* (ft NGVD)	Toe Selection
84.6 to 85.4L	**	1944	1:3	12	15	0	Yes
92.6L	177	1979	1:2	12	18	-10	Yes
94.0L	220	1985	1:2	12	18	-7	Yes
99.2R	311	1985	1:2	12	18	3	Yes
99.5L	180	1979	1:2	12	18	10	Yes

* Lowest elevation of the toe.
** See footnote, Table 4.

the low-water surface to near the top of the natural berm. Depending on maintenance practices, many of the berms were covered with vegetation of various sizes (grass to large trees). At a few locations, sediment wedges extended down into the water.

Nearly all of the cobble revetment damage appeared to be related to toe failure. These sites were characterized by an unprotected vertical channel bank surface that rose from the water, as shown in Figure 21a. The toe material at these locations was cohesive. Cobble was generally present at the top of the vertical surface, as shown in Figure 20b, and was generally found on the channel bottom adjacent to the vertical surface. (This was verified by probing with a boathook.) No upper bank problems were present at most of the sites. Usually the sediment berm above these failures was either undisturbed or had a failure plane at the location of the vertical clay face. The length and height of the damaged areas varied widely, but they were generally less than 50 ft long and 4 ft high. Other toe failures occurred as underlying bank material was removed and rock was launched along irregular failure surfaces.

Possible causes of
damage at PL-99 sites

The failure at 84.6 to 85.4L is similar to many of the damaged cobble revetments. Harvey, Watson, and Schumm (1989) provided a photograph of this site and stated that the damage was related to failure of material in underlying deposits.

Sites 92.6L, 94.0L, and 92.2L were all located on convex banks in sharp bends, and damage occurred slightly downstream of the bend apex at all three sites. Each of the bends had a low radius of curvature to channel width (r_c/W) ratio. Bagnold (1960) discussed this ratio with respect to flow separation zones. As a bend becomes tighter (lower r_c/W), the flow on the inside of the bend tends to separate from the channel bank, and an eddy is formed. These bends were tight enough that eddies could form at high stages. These eddies could remove either the revetment toe or the underlying toe materials by scour and cause failure of the upper banks. Eddies would not occur at lower stages, and the scour holes formed during high flow would fill with sand.

Findings of other investigators support the idea of flow separation-induced damage on convex bank revetments. Harvey, Watson, and Schumm (1989) observed evidence of complex stage-dependent eddies occurring in bends in the pilot study reach. Deposition on concave banks and erosion of convex banks

a. RM 108.2R

b. RM 101.3R

Figure 21. Typical cobble revetment damage observed in pilot study reach

was noted. The USAED, Sacramento (1988), reported high-flow (23,300 to 50,400 cfs) velocity measurements at RM 156.5 in March 1986. Velocity profiles were measured at several locations across the cross section, and isovels were constructed using these measurements. Peak velocities were located near the convex bank for all discharges. Faster moving flow thus moved across the point bar.

The damage at 99.2R was not related to vegetation. The site failed the year after construction, and the failure could have been related to construction problems. Some type of slip failure appeared to have occurred. Probably some type of problem at the revetment toe caused the upper bank to rotate.

Cobble revetment damage

Damaged cobble sites tended to be similar to one another. Since most of the cobble revetments were over 20 years old, exact determination of the causes of damage was very difficult. Several possible causes exist for the damage. Harvey, Watson, and Schumm (1989) provided several explanations related to geotechnical factors. The cohesive materials present at most of the sites allowed increased toe scour depths that eventually led to revetment damage. Other damage possibly occurred when bank materials were eroded from underneath the revetment and the lower portion of the revetment was launched. Failures in specific area tended to be similar, so geotechnical explanations are very realistic.

Possible causes of cobble revetment damage not related to geotechnical factors also exist. Gradual deterioration of the revetments through time is a possible explanation. Many of the older revetments were constructed without a thick toe section for launching, so damage would become visible after even a modest amount of toe scour. Construction or design errors may have resulted in cobble gradation being too small or a cobble layer that was not thick enough. Characteristics of damaged cobble revetments were similar regardless of the presence or absence of vegetation.

PART IV: PROTOTYPE REVETMENT VEGETATION AND DURABILITY

Overview

To study the association between revetment vegetation and durability during the 1986 flood, revetments in the pilot study reach were mapped. The maps depicted revetment location, material, construction date, and vegetation type from a number of sources that bracketed the flood in time. Damaged revetment segments identified as described in Part III above were also mapped. The maps were then used to build a data base with a record for each 100-ft segment of revetted bank line in the study reach. This data base was analyzed using statistical and graphical techniques.

Additional analyses were undertaken using data collected by field inspections in April 1989 (Harvey, Watson, and Schumm 1989) and in September 1989. Data collected during the 1989 inspections included revetment material, location, damage, and vegetation. Although the 1989 data are an excellent source of information regarding the current status of the revetments, they cannot be used to determine revetment performance during extreme events or to study the association between vegetation and durability during floods because undocumented repairs may have occurred between the 1986 flood and the inspections.

Compilation of Information

Since direct observations of vegetated and unvegetated revetments during the flood were not available, information from many sources had to be compiled to determine (a) what revetment damages were sustained during the flood and (b) the status of vegetation on revetments in the study reach at the time of the flood. Related factors such as revetment material, age, and location in relation to the channel planform were also of interest. Personnel in the Sacramento District and other agencies were contacted to obtain information. Data regarding 1986 flood damages were obtained as described in Part III above. Vegetative conditions were inferred from inspection reports and aerial photos bracketing the flood. Revetment locations were obtained from District files, and revetment materials were obtained from field notes provided by WET.

Selection of Aerial Photos

Catalogs of aerial photo coverage were obtained by contacting public agencies and private vendors. Table 7 is a listing of parties contacted. Indices of coverage taken between 1984 and the present at appropriate scales were obtained and used to select and order photos. To evaluate the usefulness of photos of various scales, sources, and emulsions, many coverages were ordered, most in both the original and enlarged scales. Basic preflood coverage was ordered from the US Department of Agriculture, the Sacramento District, and the WAC Corporation. This basic coverage was supplemented with partial coverage of the study area obtained from the US Geological Survey (USGS). Basic postflood coverage was obtained from the DWR (1986 Air Atlas) and the US Department of Agriculture (USDA). Coverages obtained are summarized in Table 8. A listing of the photos used in this study is provided in Appendix B.

Preparation of Overlays

Using full-size blue-line reproductions of the 1986 Air Atlas sheets (1:4,800-scale photomosaics) as a base, a series of clear acetate overlays were prepared to aid in compiling and comparing information from many sources. Blue-line reproductions of the Air Atlas sheets for the pilot reach depicting revetment locations and construction dates were obtained from Messrs. Barry Jarvis and Craig Gaines of the Sacramento District. Using permanent markers, overlays were prepared for each sheet as shown in Figure 22 and described Tables 9 and 10. Various types of revetment material, damage, and vegetation were depicted using different symbols and colors. Each overlay was provided with titles and a legend.

Various techniques were devised to ensure that the overlays would be accurate and consistent. For example, the sheets provided by Gaines and Jarvis often showed overlapping revetments. When two or more revetments overlapped, only the most recent was mapped on Overlay A. Furthermore, revetments isolated from the river (many tens of feet from the main channel) due to channel migration were ignored. Lumber mattress revetments were also ignored, since this study deals with vegetation in rock.

The April 1989 WET field notes were provided on full-size photographic reproductions of the 1986 Air Atlas sheets, and therefore it was easy to

Table 7

Parties Contacted for Aerial Photo Coverage of Pilot Study Reach

Vendor or Agency	Address	Telephone	Point of Contact	Remarks and Available Coverage
USDA ASCS APFO	PO Box 30010 Salt Lake City, UT 84130-0010	801-524-5856	Linda Cotter	Letter 22 May 89 Telecon 5 June 89 NHAP Color IR 1:58,000 (June 84) NAPP Color IR 1:40,000 (June 87)
USACE	CESPK-ED-D Sacramento, CA 95827	916-551-1905	Jim Stapleton	FAX Inquiry June 89 B&W 1:54,000 (22 May 84 Air Atlas)
Western Aerial Contractors Corp. (WAC)	520 Conger Street Eugene, OR 97402-2795	503-342-5169	Michael Renslow	Telecon 19 May 89 B&W 1:31,680 (17-20 March 84)
DWR	PO Box 942836 1416 9th St., Rm 215-23 Sacramento, CA 94236-9259	916-445-9259 916-445-9287	Joey Wong Cindy Beach	Telecon 19 May 89 B&W (4 Nov 86 Air Atlas)
USGS EROS Data Center	EROS Data Center Sioux Falls, SD 57198	605-594-6151	Customer Services	B&W and Color Feb 86 Flood NASA Color IR 1:62,000 Mar, Jul, Sept 85
Moffett Field	Aimes Research Center	415-694-3326	Bryan Wood	Info about NASA Coverage
USGS National Cartographic Information Center	507 National Center Reston, VA 22092	703-860-6045	--	Letter of Inquiry 8 May 89 1984 and 1987 NHAP and NAPP
California Attorney General	--	916-323-1438	Don Young	Telecon 12 May 89 Annual June Coverage Upstream of Tisdale Weir 1:12,000
Air Flight Service	2220 Calle de Luna Santa Clara, CA 95054	408-988-0107		
American Aerial Surveys	6249 Freeport Blvd. Sacramento, CA 95827	916-442-0770		Letter of Inquiry 8 May 89
Cal Aero Photo	2859 Gentry Court Sacramento, CA 95827	916-363-4790		Letter of Inquiry 8 May 89
Cartwright Aerial Surveys	6141 Freeport Blvd. Sacramento, CA 95822	916-421-3465		Letter of Inquiry 8 May 89
CH2M Hill	PO Box 2088 1525 Court St. (96001) Redding, CA 96099	916-243-5831		Letter of Inquiry 8 May 89
Radman Aerial Surveys	6220 24th Street Sacramento, CA 95822	916-391-1651		Letter of Inquiry 8 May 89 Reply 24 May 89 B&W 1:24,000 (May 77 and June 86)
Aerial Data Systems	1127 Gray Ave, Suite B Yuba City, CA 95991	916-673-1430		Letter of Inquiry 8 May 89
California Office of Emergency Service	2800 Meadow Road Sacramento, CA 95832	916-427-4216		Referred by USGS NCIC, 1:32,000 Color, Color IR, and B&W Feb 1986 Flood

Table 8

Photo Coverages Obtained for Pilot Study Reach

Date	Original Scale	Type	Source	Producing Agency
		Preflood		
June 1984	1:58,000	Color IR HAP	USDA ASCS APFO	USGS
March 1984	1:52,800	Black and white	Sacramento District	CE
May 1984	1:31,680	Black and white	WAC Corp.	WAC Corp.
mid-1985	1:62,000	Color IR	Eros Data Center	NASA
		Postflood		
November 1986	1:24,000	Black and white	Sacramento District	DWR
June 1987	1:40,000	Color IR NAPP	USDA ASCS APFO	USGS

transfer information from these notes to overlays at the same scale. On the other hand, the inspection records (provided as Appendix C) are tables, not maps. The inspection forms note the occurrence of "growth in rock revetment" and give the location to the nearest 0.01 levee mile. Using the levee log to determine the levee mile location of various landmarks and a digitizer to measure distances, the "growth in rock" locations were transferred to the B overlays. The digitizer used in this study was a Geographics drafting board digitizer with Measugraph software running on an IBM PC/XT microcomputer. Digitizer accuracy was 0.00125 in.

The PL-99 files often provided less than ideal information regarding location and extent of damages. Sketches and photos from the files were used to locate the damages. In order to conservatively emphasize the effect of vegetation on damage, damage zones were made larger rather than smaller when they could not be precisely located.

Overlays D and E were not prepared directly from the aerial photographs because the photos were of widely varying scales and were uncontrolled. Instead, vegetation was located on these photos by stereo interpretation of enlarged and original scale photos and by study of enlargements. Vegetation locations were then transferred to a clear overlay mounted on top of the appropriate 1986 Air Atlas sheet. The blue-line Air Atlas sheets had remarkable resolution, and often the photointerpretation simply clarified interpretation of the Atlas sheets. All significant vegetation growing on revetments was mapped, even isolated individuals. Vegetation was mapped as Type 1

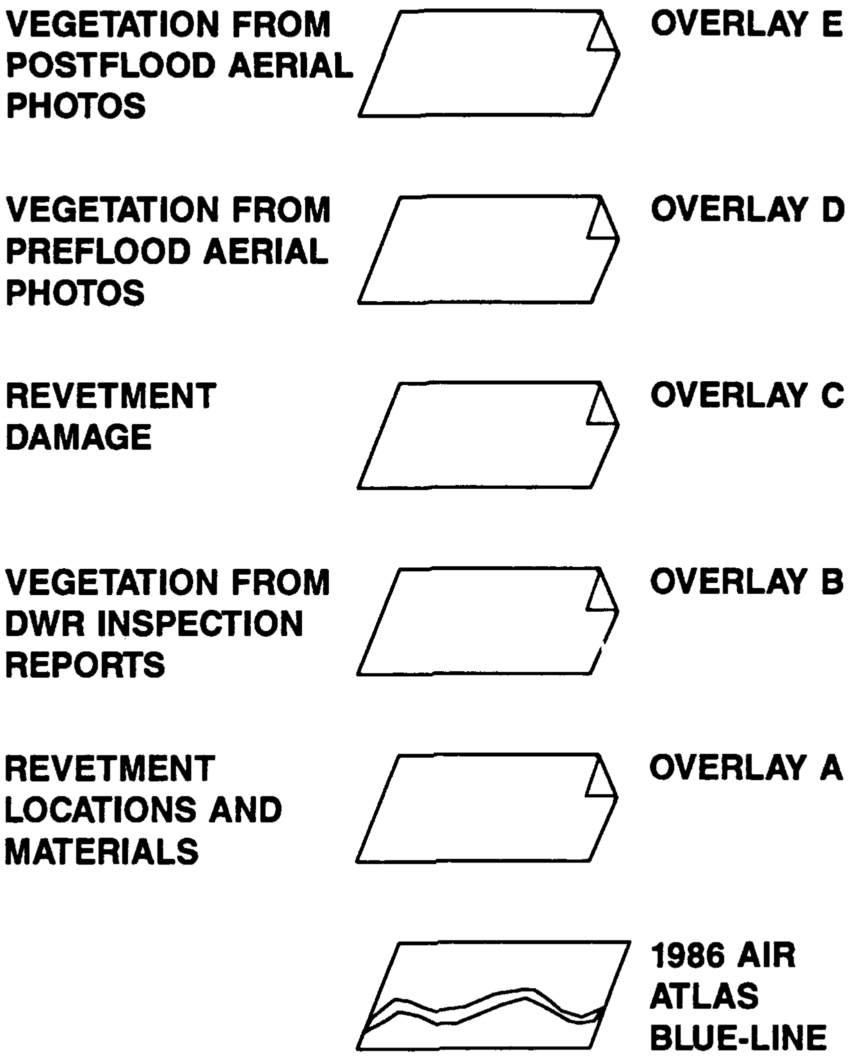


Figure 22. Schematic of overlays used to map pilot study reach

(bare rock or soil or very low herbaceous growth), Type 2 (woody trees and shrubs more than about 4 ft but less than about 12 ft high), or Type 3 (woody vegetation larger than Type 2). Crown size, texture, length of shadows, and stereo interpretation were all used to determine the appropriate category for vegetation. When trees or shrubs occurred as isolated individuals rather than dense stands, the largest individual within a 100-ft segment was used to determine the vegetation type. For example, a single 20-ft tree growing among smaller vegetation was mapped as Type 3. This approach was taken to emphasize effects of vegetation. An effort was made to avoid mapping trees growing on the berm but not those on or in the revetment.

Table 9

Overlays Prepared for 1986 Air Atlas Showing Revetment Damage and Vegetation

Overlay	Descriptions	Sources	Categories
A	Revetment locations, revetment materials	Overlays from Gaines and Jarvis April 1989 WET field notes	Cobble Rock riprap Concrete rubble Unrevetted bank line
B	Vegetation growing in or on revetment	DWR inspection reports (Forms 167) for fall 1985 and spring 1986	Fall 1985--berries --trees Spring 1986--berries --trees
C	Revetment damage	PL-99 Emergency Assistance Requests April 1989 WET field notes	Damage from PL-99 files Damage from WET notes
D	Vegetation on revetment from preflood aerial photography	March 1984 WAC black-and-white June 1984 NHAP color IR March, July, Sept 1985 NASA color IR	Type 2 vegetation Type 3 vegetation
E	Vegetation on revetment from postflood aerial photography	DWR 1986 Air Atlas black-and-white Spring 1987 NAPP color IR	Type 2 vegetation Type 3 vegetation

Table 10

Overlays Prepared for Pilot Reach

Overlay	1986 Air Atlas Sheet 45	46	47	48	49	50	51	52	53	54	55
A (revetments)	X	X	X	X	X	X	X	X	X	X	X
B (inspections)	X	X	-	-	X	X	-	X	-	X	-
C (damage)	X	-	X	-	X	X	X	X	X	-	X
D (preflood veg)	X	X	X	X	X	X	X	X	X	X	X
E (postflood veg)	X	X	X	X	X	X	X	X	X	X	X

Dash (-) means no vegetation or damage shown on that sheet, and therefore no overlay was prepared.

Notes regarding the utility of each of the aerial photo coverages obtained for this study are presented in Appendix D. When preflood photos were inconsistent with respect to vegetation locations or sizes, the WAC Corporation 1984 black-and-white enlargements were used as the controlling source of information. In similar fashion, the 1986 Air Atlas black-and-white enlargements were used as the controlling source of information for postflood vegetation.

Maps from 1989 Inspection

During the course of the study, the Sacramento District requested that the study team conduct a field inspection of the pilot study reach. Since so little damage was recorded in the 1986 PL-99 files, it was decided to use this field inspection as an opportunity to record all revetment damage in the study at the time of the inspection, regardless of how minor it might be. Revetment damage reported by Harvey, Watson, and Schumm (1989) in their WET field notes was included on Overlay C. Half-size photographic reproductions of the Air Atlas sheets showing locations and Overlay C were taken to the field. The entire pilot reach was carefully inspected from a boat during 25-27 September 1989, and revetment damage and vegetation were mapped on these sheets using colored markers.

Additional Information from 1989 Inspection

Detailed field notes, still photographs, and videotape were also generated during the September 1989 inspection of the pilot reach. Observations of revetment damages were described in Part III. Samples (either cores or slices) were obtained using procedures prescribed by Schweingruber (1988) from selected trees growing on revetments to characterize the range of tree sizes and ages found in the pilot reach. Trunk diameters of sampled trees were measured also. Results are shown in Table 11. Age determinations were complicated by core fracturing and possible false rings, but a range of ages was estimated by Dr. C. V. Klimas of the US Army Engineer Waterways Experiment Station (WES). Estimated ages for Type 2 trees ranged from 2 to 7 years; diameters ranged from 0.3 to 2.4 in. Estimated ages of Type 3 trees ranged from 7 to 80 yrs; diameters ranged from 9.6 to 51.3 in. In all cases, estimated tree ages were consistent with revetment construction dates. All of the Type 3 individuals and three of the five Type 2 individuals were old enough to have been present during the 1986 flood.

Preparation of Data Bases

The overlays and maps described above were used to produce two data bases. The first data base contained damages from PL-99 files and information about revetment vegetation from the aerial photos and DWR inspections before and after the 1986 flood. The second data base contained information from the 1989 field inspections.

1986 data bas.

Locations of revetments, vegetation, and revetment damage relative to fixed reference points were determined by measuring distances on the overlays with a digitizer. Information from the overlays was entered into a microcomputer spreadsheet. Each row in the spreadsheet represented a 100-ft segment of revetted bank line as shown in Figure 23. A column was included that contained a number indicating the position of each 100-ft revetted bank-line segment with respect to channel planform (bank curvature). Columns in the spreadsheet included those shown in Table 12. The data base also included a column for river mile labels and remarks. A portion of the data base is presented in Appendix E.

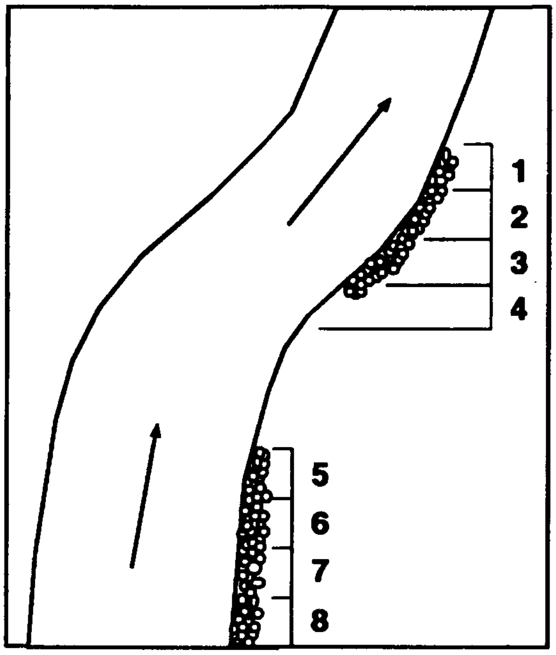
Table 11

Woody Vegetation Sampled from Pilot Study Reach Revetments, September 1989

Sample No.	River Mile	Construction Date	Species	Estimated Age* years	Vegetation Type	Sample Type	Diameter in.	Remarks
				Vegetation Types 1 and 2				
C4	88.2R	1979	Willow	5-7	2	Cored	2.4	Riprap revetment
C4	88.2R	1979	Willow	5	2	Cut	0.8	Riprap revetment
C5	93.2R	1974	Maple	5-7	2	Cored	1.6	Riprap revetment
C8	107.5R	1956	Cottonwood	3-4	2	Cored	2.0	Cobble revetment
C8	107.5R	1956	Cottonwood	2-3	2	Cut	0.3	Cobble revetment
				Vegetation Type 3				
C6	100.0R	1939	Cottonwood	35-55	3	Cored	43.0	Cobble revetment overlaid with silt-clay deposits
C3	85.6R	Unknown	Cottonwood	40-80	3	Cored	51.3	Cobble revetment overlaid with silt-clay deposits
C10	115.3R	1974	Ash	7-11	3	Cored	9.6	Riprap revetment, multiple trunks
C2	139.5L	1968	Willow	10-20	3	Cored	10.7	Cobble revetment
C1	140.3R	1950	Cottonwood	20-40	3	Cored	24.6	Cobble revetment
	140.3R	1950	Cottonwood	-	3	None	22.5	No core, no estimate of age; cobble revetment
	140.3R	1950	Cottonwood	-	3	None	17.0	No core, no estimate of age; cobble revetment

* Age estimates provided by Dr. C. V. Klimas, WES.

MAP



DATA BASE

SEGMENT NO.	DISTANCE	REVET ID	CONST DATE
1	160,000	112.1R	1967
2	160,100	112.1R	1967
3	160,200	112.1R	1967
4	160,300	112.1R	1967
5	164,280	113.5R	1977
6	164,380	113.5R	1977
7	164,480	113.5R	1977
8	164,580	113.5R	1977

"DISTANCE" IS DISTANCE BETWEEN THE UPSTREAM END OF THE FREMONT WEIR AND THE DOWNSTREAM END OF THE 100-FT SEGMENT MEASURED ALONG THE BANK LINE ON THE 1986 AIR ATLAS.

Figure 23. Relationship between maps and data base

1989 data base

The second data base was constructed essentially by adding observations from the WET field notes and from the September 1989 inspection maps to the columns from the first data base containing distance, revetment identifier, year, material, planform, and bank (Table 12). Observations from the WET notes were entered as a single column with each segment designated as damaged or undamaged. Observations from the September 1989 inspection maps were entered as two columns: one for damage (damaged or undamaged) and the other for vegetation (Type 1, 2, or 3 as on Overlays D and E).

Analysis of Data Bases

Relationships among the variables in the data base were explored using descriptive statistics and cross-tabulation. Computations were performed using the Statpro statistical analysis program (Penton Software, Inc. 1985). Results of the cross-tabulations were summarized in tables and figures. Plots were produced to depict spatial relationships between vegetation and damage.

Table 12

Information Columns for 1986 Flood Damage Data Base

Name	Description
Distance	Distance in feet from the downstream end of the segment to the upstream end of the Fremont Weir measured along the bank line on the 1986 Air Atlas
Revetment ID	A river mile identifier (e.g., 84.6L)
Year	Construction date from Gaines and Jarvis
Material	Rock riprap, river cobble, or rubble
Fall 1985 Inspection	From overlay B
Spring 1986 Inspection	From overlay B
Damage	Damage from PL-99 files for the 1986 flood
Preflood vegetation	From aerial photos
Postflood vegetation	From aerial photos
Planform	Location of segment with respect to channel planform (straight reach = 1; concave bank, bend entrance = 2; concave bank, bend exit = 3; convex bank, bend entrance = 4; convex bank, bend exit = 5).
Bank	Left or right

Results

Vegetation and 1986 flood damage

The 1986 Air Atlas sheets with overlays prepared by Gaines and Jarvis showed that approximately 248,900 ft (47.1 miles) of revetted bank line in the pilot study reach were constructed prior to 1986. Since the pilot study reach is about 35.6 miles long, about 66 percent of the bank line was revetted at the time of the flood. Sixty-nine percent of the revetted bank line was cobble, 30 percent was stone riprap, and less than 1 percent was rubble. Four of the five WET subreaches that coincide with the pilot reach had more cobble that riprap, with the percentage of cobble ranging from 54 to 81. In contrast, revetted bank lines in WET subreach 4 were almost 80 percent riprap.

About 20 percent of the pilot reach revetment was in straight reaches, 47 percent on concave banks, and 33 percent on convex banks.

Only a small fraction of the revetted bank line supported woody vegetation. Table 13 presents a synopsis of the fall 1985 and spring 1986 inspection records for the pilot study reach. The percentage of revetted bank line in the pilot study reach supporting woody vegetation obtained from both inspection records and aerial photos is shown in Table 14 and Figure 24. The percentages based on inspection records shown in Table 14 are greater than would be obtained by dividing the totals from Table 13 by the length of revetted bank line in the pilot reach (248,900 ft) because 100-ft revetment segments were coded into the data base as vegetated even if vegetation covered only part of the segment.

The discrepancy between the amount of vegetation reported by inspectors and that observed on aerial photos shown in Table 14 and Figure 24 is noteworthy. While only 20 of the 100-ft segments that were reported as vegetated by inspectors were classified as Type 1 based on aerial photography, 182 segments not noted by inspectors were classified as Type 2 or 3. Cross-tabulation revealed that about two-thirds of the revetments with unreported vegetation were cobble. Forty-seven percent of unreported preflood revetment vegetation was in Reclamation District 1500. Forty-two percent of the unreported postflood revetment vegetation was in the Sacramento River West Side Levee District.

Based on aerial photographs, woody vegetation on revetments decreased slightly between preflood and postflood photo dates. Woody vegetation was found on 10.8 percent of the revetted segments preflood but only 9 percent postflood. This change may have been caused by the flood scouring away vegetation or by a spurt of maintenance activity; the exact cause cannot be determined with available information.

According to the PL-99 files, damage was recorded for only 2.2 percent (54) of the 100-ft increments. Twenty-nine of these were cobble sites, and 25 were rock riprap. The PL-99 files report about 460 ft of damage at four riprap sites and about 4,200 ft of damage at 84.6 to 85.4L,* which was

* The PL 84-99 file for this site indicated that damage extended along "the entire length of the revetment" at this location (84.6 to 85.4L). Accordingly, this entire region was mapped and coded into the 1986 data base as damaged. However, field inspection in April (Harvey, Watson, and Schumm 1989) and September 1989 revealed that damage was limited to about 900 ft from 84.7 to 84.9L. The lower number (900 ft) was used in the 1989 data base.

Table 13

Growth in Rock Revetment from DWR Inspection Form 167 for Pilot Study Reach

Date	Local Interest	Location of Wild Growth in Rock From L.M.	to L.M.*	Length of Segment ft	Comments
Sep 85	Reclamation District No. 1500	15.77	15.85	422	Trees, berries, and bamboo
		20.88	20.90	106	
		22.95	22.96	53	
		24.05	24.07	106	
		24.88	24.89	53	
		25.05	25.06	53	
		31.74	31.75	53	
			Subtotal	844	
Oct 85	Sacramento R. West Side Levee District	No wild growth noted			
Oct 85	Yolo County Service Area No. 6	0.40	0.43	158	
		0.62	0.66	211	
		2.35	2.45	528	
		2.92	3.23	1,637	
		3.34	3.45	581	
		3.88	3.98	528	
		4.34	4.37	158	
		5.52	5.75	1,214	
			Subtotal	5,016	
Apr 86	Reclamation District No. 1500	5.77	15.82	264	Berries and bamboo
		20.88	20.90	106	
		22.95	22.96	53	
		24.05	24.07	106	
		24.88	24.89	53	
		25.05	25.06	53	
		31.74	31.75	53	
			Subtotal	686	
May 86	Sacramento R. West Side Levee District	No wild growth noted			
Apr-86	Yolo County Service Area No. 6	2.35	2.36	53	
		2.38	2.56	950	
		3.34	3.45	581	
			Subtotal	1,584	
			Total, fall 1985	5,860	
			Total, spring 1986	2,270	

* Levee miles.

Table 14

Percent of Revetted Bank Line Segments in

Pilot Reach with Vegetation

Source	Vegetation	Vegetation	Vegetation
Fall 1985 inspection records	--	--	3.0
Spring 1986 inspection records	--	--	1.7
Preflood aerial photos	5.5	5.3	10.8
Postflood aerial photos	4.8	4.3	9.0

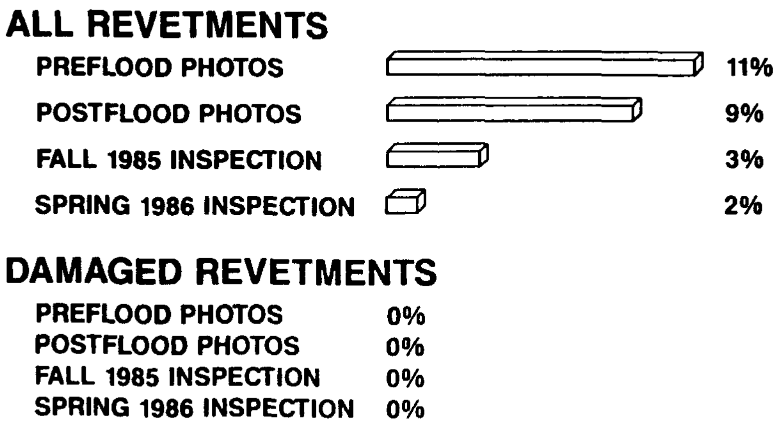


Figure 24. Percentage of revetted bank line in pilot study reach supporting woody vegetation

partially cobble and partially riprap, for a total of 4,660 ft. Just as for vegetation, the length of damage from the data base (5,400 ft) is inflated because segments were coded as damaged even if only part of the segment sustained damage. Furthermore, when damaged sites could not be precisely located, a series of segments covering the approximate location were classified as damaged. All sites described as damaged in the PL-99 requests for the pilot reach were coded as damaged even though only one site was ever repaired.

Not counting 84.6 to 85.4L, 92 percent of the damaged segments were riprap revetments located on convex banks. Aside from 84.6 to 85.4L, 96 percent of the damaged segments were constructed subsequent to 1970. All of the damaged sites were located below mile 100, and 50 of the 54 damaged segments were on the left bank (Figure 25).

Vegetation types for undamaged and damaged revetments are compared in Figure 26. None of the four sources of information about revetment vegetation indicated any woody vegetation on any of the damaged segments before or after the 1986 flood. Accordingly, damage rates for unvegetated sites were higher than for vegetated ones. Damage rates for various revetment categories are presented in Table 15.

Vegetation and damage in 1989

Approximately 262,400 ft (49.7 miles) of revetted bank line was mapped in September 1989, about 2.6 miles more than was included in the first data base. Sixty-five percent of the revetted bank line was cobble, 34 percent was rock riprap, and about 1 percent was rubble, indicating that essentially all of the revetment added since 1986 was rock riprap. Revetment occurring on convex banks was 34 percent, up from 32 percent in 1986. Woody vegetation was observed on about 11 percent of the revetted bank line segments in 1989, which compares with 8 to 10 percent from aerial photos taken before and after the flood. Field inspection yielded higher values because even isolated saplings were noted. About 7 percent of the revetment had Type 2 vegetation, and about 4.5 percent had Type 3.

All visible signs of damage (such as slightly displaced stone) were recorded during the 1989 inspection. About 3.8 percent of the revetted bank line was classified as damaged. Seventy-six percent of the damaged segments were cobble; 69 percent were constructed before 1970. Table 16 shows damage and vegetation rates for several categories.

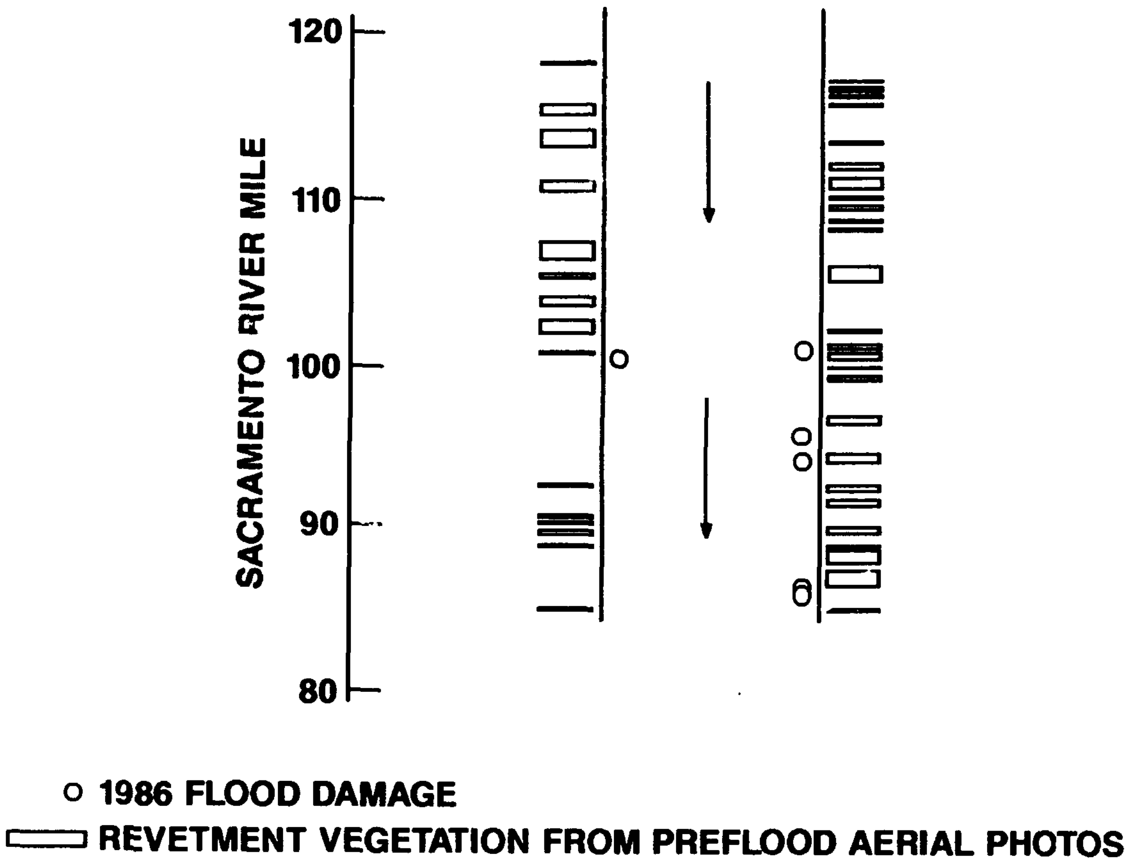


Figure 25. Schematic of pilot study reach, Sacramento River, showing PL-99 damage sites and preflood revetment vegetation from aerial photographs

Damage rates for revetments supporting Types 2 and 3 vegetation were 5.4 and 9.5 percent, respectively, which compares to only 3.3 percent for those supporting Type 1 vegetation. However, this association between woody vegetation and damage is due to the association between revetment age, bank curvature and damage. To better assess the nature of the association between vegetation and revetment durability, a cross-tabulation of data base 2 (1989 conditions) was performed using two vegetation classes (Type 1 and Type 2 or 3), two damage classes (undamaged or damaged), three bank curvature classes (straight, concave, and convex), and three age classes. This cross-tabulation was run for all revetments, for cobble revetments only, and for rock riprap revetments only. Results are shown in Table 17 and Figure 27. Vegetated revetments performed as well or better than unvegetated revetments in seven of nine categories when all types of material were considered. Vegetated cobble revetments performed as well or better than unvegetated in six of nine

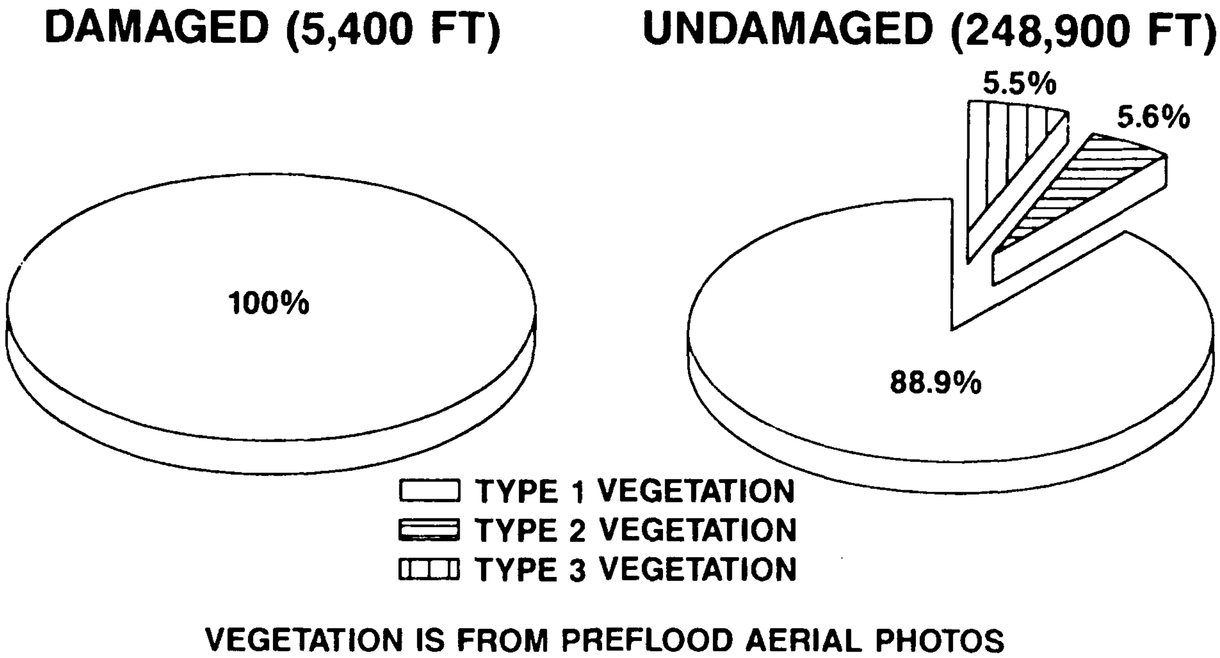


Figure 26. Distribution of vegetation types on damaged and undamaged revetments

categories, and vegetated riprap revetments performed as well or better than unvegetated in five of six categories. When vegetated and unvegetated revetments of similar age and with similar locations within bends were compared, vegetated revetments were less likely to be classified as damaged than unvegetated revetments.

Comparison of Findings--1986 and 1989

Results obtained from cross-tabulation analyses of the two data bases are compared in Table 18. The 1989 data base includes more damage and more types of damage situations, although it does not provide any information about structure performance under a given set of hydraulic conditions. Aside from 84.6 to 85.4L, the PL-99 data base emphasizes damage to relatively new rock riprap sites on convex bank. The 1989 data base records damage to old cobble sites that was not recorded in PL-99 files. Many of these sites are located on concave bend exits or convex bend entrances. Both data bases revealed that older revetments were more likely to support woody vegetation (Figure 28). Both also indicated no relationship between the amount of vegetation and the amount of damage in a WET subreach (Figure 29).

Table 15

Revetted Bank Line Damage and Vegetation by Category, Based on 1986 PL-99 Files and Preflood Aerial Photography

	Percent Damaged	Vegetation, Percent Type 1	Type 2	Type 3
Vegetation				
Type 1	2.4	100	0	0
Type 2	0.0	0	100	0
Type 3	0.0	0	0	100
Material				
Cobble	1.7	90	6	4
Riprap	3.3	87	4	9
Planform				
Straight	0.2	89	4	7
Concave bank				
Entrance	1.3	95	3	2
Exit	1.1	87	6	6
Convex bank				
Entrance	4.0	85	9	6
Exit	5.9	89	6	5
Construction Date				
Pre-1960	2.4	89	8	3
1960-69	0.0	90	6	4
1970-79	2.5	90	3	7
1980-present	24.0	100	0	0
WET subreach				
3	16.5	79	6	15
4	0.0	89	5	6
5	1.5	92	5	3
6	1.0	84	8	8
7	0.0	94	4	2

Cross-tabulation of the 1986 data base by planform revealed that convex bank revetments were slightly more likely to support woody vegetation than concave bank revetments (Table 15). The 1989 data base (Table 16) also indicated that vegetation rates for convex banks were greater, but the difference between convex and concave banks was less than for the preflood data. The preflood data set (Table 15) indicated that only 5 percent of the revetted segments on concave banks in bend entrances supported woody vegetation.

Table 16

Revetted Bank Line Damage and Vegetation by Category

Based on September 1989 Field Inspection

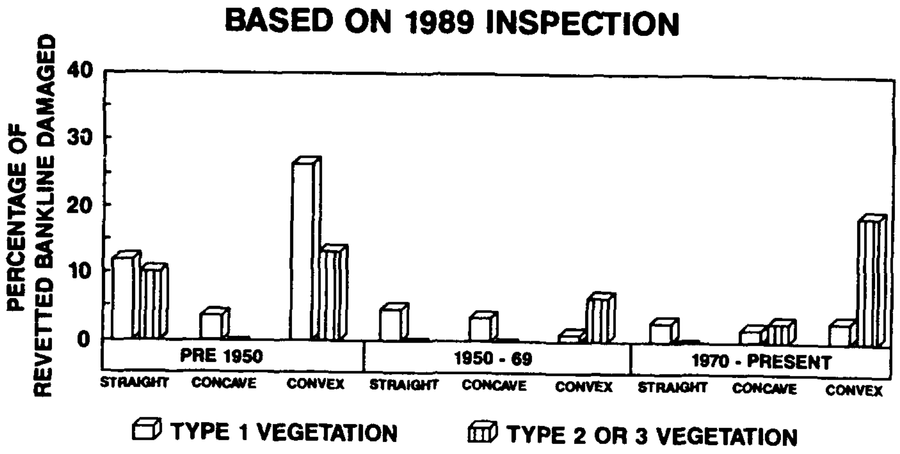
	Percent Damaged	Vegetation, Percent Type 1	Type 2	Type 3
Vegetation				
Type 1	3.3	100	0	0
Type 2	5.4	0	100	0
Type 3	9.5	0	0	100
Material				
Cobble	4.4	91	6	3
Riprap	2.7	81	11	8
Planform				
Straight	4.2	87	7	6
Concave bank				
Entrance	0.9	89	7	4
Exit	5.9	88	9	3
Convex bank				
Entrance	6.4	87	8	5
Exit	0.3	86	8	6
Construction Date				
Pre-1960	5.0	92	5	3
1960-69	2.8	96	3	1
1970-79	2.5	85	10	5
1980-present	3.4	83	8	9
WET subreach				
3	9.7	77	7	16
4	0.0	66	14	20
5	0.5	91	6	3
6	5.2	83	12	5
7	3.2	93	5	2

Eleven percent of these segments supported some type of woody vegetation in 1989 (Table 16).

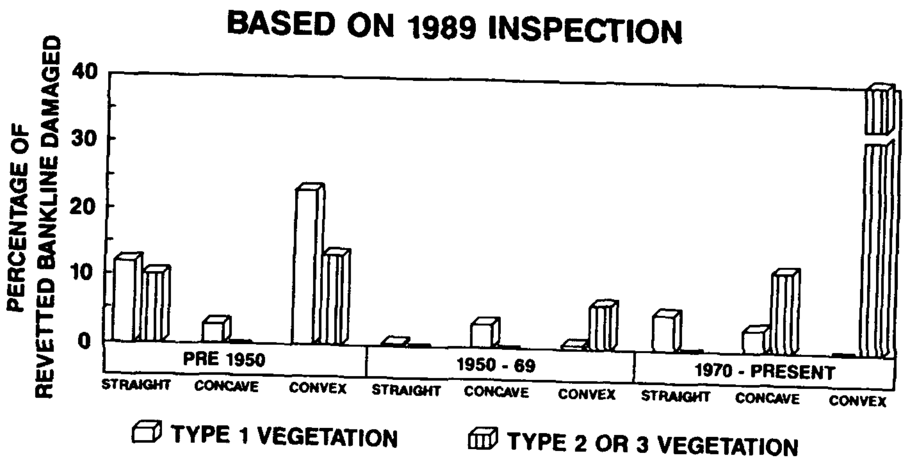
Table 17

Damage Rates for Categories Based on Material, Construction Date, and Bank Curvature (Data Base 2 - 1989 Conditions)

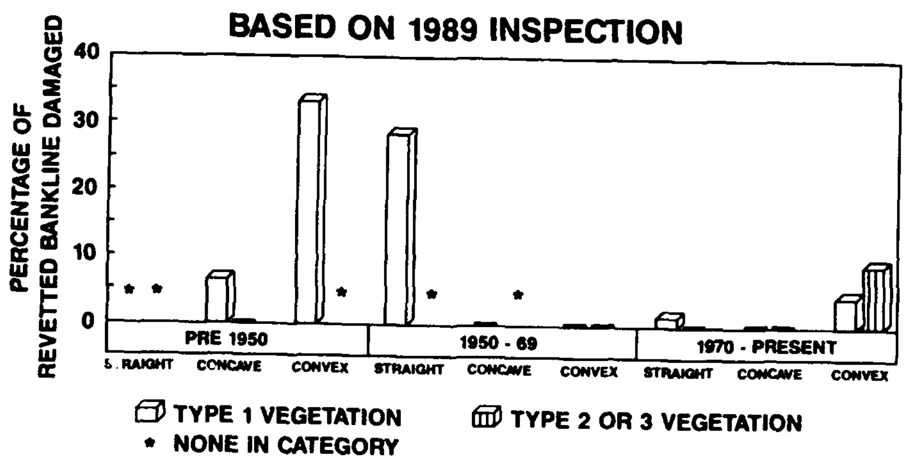
		Type 1			Type 2 or 3		
Construction Date	Bank Curvature	No. Damaged	Total No.	Percent Damaged	No. Damaged	Total No.	Percent Damaged
			All Revetments				
Pre-1950	Straight	3	25	12.00	1	10	10.00
Pre-1950	Concave	4	111	3.60	0	9	0.00
Pre-1950	Convex	5	19	26.32	2	15	13.33
1950-69	Straight	9	207	4.35	0	6	0.00
1950-69	Concave	18	620	2.90	0	25	0.00
1950-69	Convex	3	407	0.74	2	33	6.06
1970-present	Straight	5	193	2.59	0	46	0.00
1970-present	Concave	6	357	1.68	2	82	2.44
1970-present	Convex	9	318	2.83	5	27	18.52
			Cobble Revetments				
Pre-1950	Straight	3	25	12.00	1	10	10.00
Pre-1950	Concave	3	96	3.13	0	4	0.00
Pre-1950	Convex	3	13	23.08	2	15	13.33
1950-69	Straight	1	179	0.56	0	4	0.00
1950-69	Concave	18	526	3.42	0	25	0.00
1950-69	Convex	3	365	0.82	2	31	6.45
1970-present	Straight	3	55	5.45	0	4	0.00
1970-present	Concave	6	177	3.39	2	17	11.76
1970-present	Convex	0	116	0.00	3	5	60.00
			Rock Riprap Revetments				
Pre-1950	Straight	0	0	--	0	0	--
Pre-1950	Concave	1	15	6.67	0	5	0.00
Pre-1950	Convex	2	6	33.33	0	0	--
1950-69	Straight	8	28	28.57	0	2	0.00
1950-69	Concave	0	94	0.00	0	0	--
1950-69	Convex	0	42	0.00	0	2	0.00
1970-present	Straight	2	138	1.45	0	42	0.00
1970-present	Concave	0	180	0.00	0	65	0.00
1970-present	Convex	9	202	4.46	2	22	9.09



a. All revetments



b. Cobble revetments



c. Riprap revetments

Figure 27. 1989 revetment damage rates for vegetated and unvegetated revetments

Table 18

Percent of Revetted Bank Line Classified as Damaged by Category, 1986 and 1989 Data Bases

	1986	1989
Vegetation		
Type 1	2.4	3.3
Type 2	0.0	5.4
Type 3	0.0	9.5
Material		
Cobble	1.7	4.4
Riprap	3.3	2.7
Planform		
Straight	0.2	4.2
Concave bank		
Entrance	1.3	0.9
Exit	1.1	5.9
Convex bank		
Entrance	4.0	6.4
Exit	5.9	0.3
Construction Date		
Pre-1960	2.4	5.0
1960-69	0.0	2.8
1970-79	2.5	2.5
1980-present	24.0	3.4
WET subreach		
3	17.0	9.7
4	0.0	0.0
5	1.5	0.5
6	1.0	5.2
7	0.0	3.2

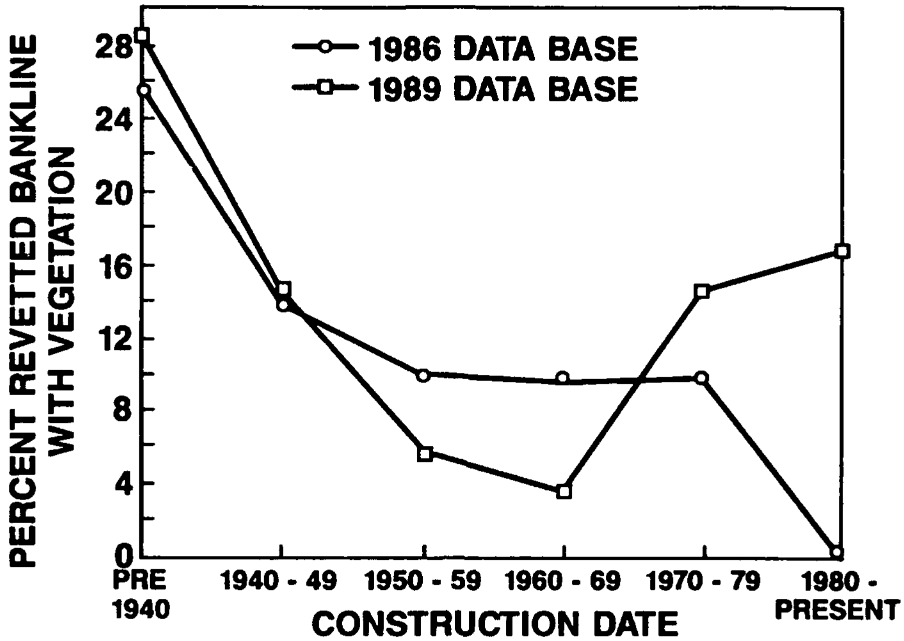


Figure 28. Percent of revetted bank line segments with Type 2 or 3 vegetation versus revetment construction date

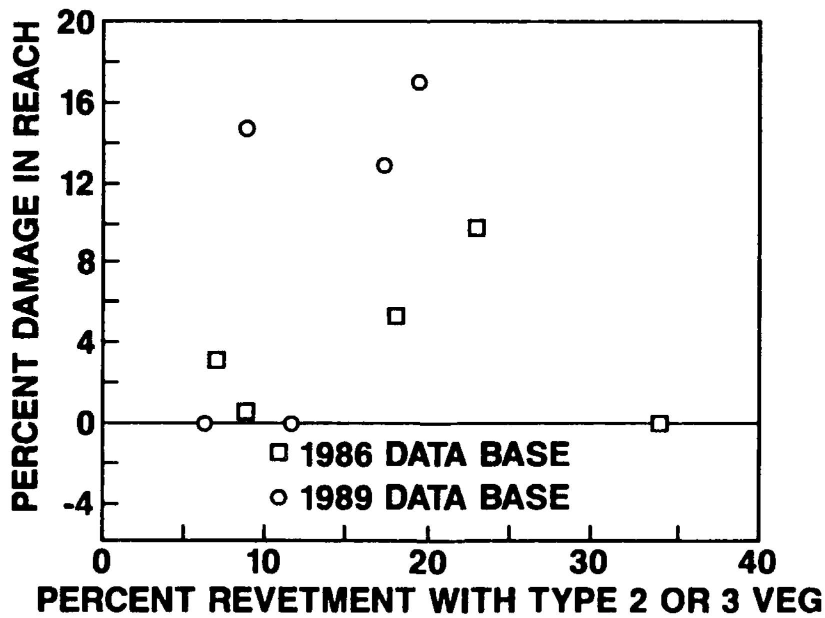


Figure 29. Damage and vegetation rates by WET subreach

PART V: DISCUSSION

The results of this study should be applied with care. Although the methods that were developed and employed were sound, only about 35 of the 194 miles of the SRBPP reach of the Sacramento River were included; none of the other SRBPP channels were included The Sacramento River undergoes striking changes in hydrologic, morphologic, and hydraulic characteristics from one end of the SRBPP reach to the other. Furthermore, maintenance of revetment vegetation potentially affects channel conveyance and project inspectability; as noted above, these issues were beyond the scope of this effort.

Changing conveyance of any of the SRFCP channel segments potentially involves issues of structural integrity and safety because project operation depends on diversion of floodwaters over weirs (most of which are ungated) into the bypasses. The impact of additional revetment vegetation on the division of flow between the river and the bypasses should be carefully considered. Admittedly, this impact might be either desirable or negligible.

Literature

Literature regarding effects of volunteer vegetation on revetment durability is scarce, as it is for many civil engineering problems involving vegetation. The literature does underscore the biological value of woody vegetation on riverbank revetments and the role of woody vegetation in controlling bank erosion on smaller rivers. Several sources attest to the positive effects of living woody vegetation (usually planted) growing through revetments on revetment stability.

Institutional Concerns

Riparian habitat is a diminishing and increasingly valuable resource in the Sacramento River Basin. Since woody vegetation growing on Sacramento River revetments constitutes riparian habitat, its removal is quite controversial. If maintenance guidelines could be relaxed or refined, mitigation requirements for revetment construction might be reduced, as noted by Harvey, Watson, and Schumm (1989).

At least some of the controversy over revetment vegetation stems from ambiguous maintenance guidelines. Growth of woody vegetation on revetments is not specifically prohibited by Federal or CE regulations or by the Standard Operation and Maintenance Manual for the SRBPP (USAED, Sacramento 1955). Removal of woody vegetation from levee slopes and from flood control channels is required, but vegetation on revetted berms is not addressed. If the phrases dealing with removal of vegetation from flood control channels were applied to the Sacramento River, even unprotected banks would have to be cleared. Language in these regulations reflects the tone of the times in which they were written: they attempt to emphasize safety and reliability at reasonable cost, and environmental maintenance objectives are absent.

Inspectors completing DWR Form 167 reported only about 20 percent of the woody revetment vegetation found in the pilot study reach in fall 1985 and spring 1986. Reasons for this discrepancy are unknown, but may include the fact that many revetments are partially or totally hidden under sediment deposits that support vegetation. During the September 1989 inspection of the pilot reach, many revetment locations had to be verified by probing or excavating 1 to 6 ft of sediment deposits. Other possible reasons for underreporting revetment vegetation include the aforementioned ambiguity of maintenance requirements, a desire on the part of local interests to indicate a high level of compliance with maintenance standards, and a lack of interest in inspecting older revetments (two thirds of the unreported vegetation was on cobble revetments).

Comparison with Results of Others

About 70 percent of the pilot reach bank line was revetted in September 1989; this figure compares with 41 percent for the reach between RM 78 and 178 (Harvey, Watson, and Schumm 1989) and 75 percent for the reach below Sacramento (Jones and Stokes Associates, Inc. 1987). In September 1989, 7 percent of the revetted bank line in the pilot reach supported Type 2 vegetation; 4.5 percent supported Type 3. Previous investigators (Snow 1987, Dehaven and Michny 1987) found that 5 to 13 percent of the revetted bank lines in other reaches supported woody vegetation. Using the most liberal definition of damage, 3.8 percent of the revetment (99 of the 100-ft segments) in the pilot reach was classified as damaged in September 1989. Only about 2.4 percent of the revetment (62 of the 100-ft segments) was marked as damaged on the WET field notes from April 1989. Comparison of the two damage tallies is provided in Figure 30. Essentially all of the WET damage was included in the WES September inspection results, and 44 additional 100-ft segments were also identified as damaged. The seven segments classified as damaged by WET but undamaged by WES were due primarily to subjective differences.

Revetment Durability

Despite the fact that many reaches of the Sacramento River experienced record or near-record discharges approaching or exceeding design conditions (USAED, Sacramento 1987), only six instances of revetment damage due to the flood were documented. None of the five damage sites located in the pilot reach were vegetated before or after the flood; the sixth site (187.1R) was recently constructed and therefore unvegetated. Only one of the five damaged sites in the pilot reach had been repaired by September 1989; all were providing adequate protection at that time. The stability of revetments in the pilot reach appears to be related to the overall stability of the channel and the relatively low velocities that occur during floods. Documented mean flood flow velocities ranged from 3 to 4.4 fps; corresponding maximum velocities are probably within the 4- to 7-fps range.

Minor damage, or fretting, was common on cobble revetments throughout the pilot study reach. This type of damage, where the lower portion of the revetment moves downward to expose 1 to 3 ft of vertical cohesive bank just above normal low-water elevation, is apparently related to toe failure and geotechnical factors. Although about 3 percent of the revetted bank line in the pilot reach exhibited this type of damage, the safety and stability of the revetments did not seem to be impaired. The type of revetment damage previously identified as potentially caused by vegetation (scour adjacent to tree trunks, root wad removal by windthrow) was not observed in the September 1989 inspection. However, a large windthrown cottonwood was observed on a cobble revetment on an approach channel to one of the weirs in February 1989 (Figure 7).

Revetment Vegetation and Durability

Existing aerial photographs and inspection reports were adequate to establish the types of vegetation found on revetments during the 1986 flood.

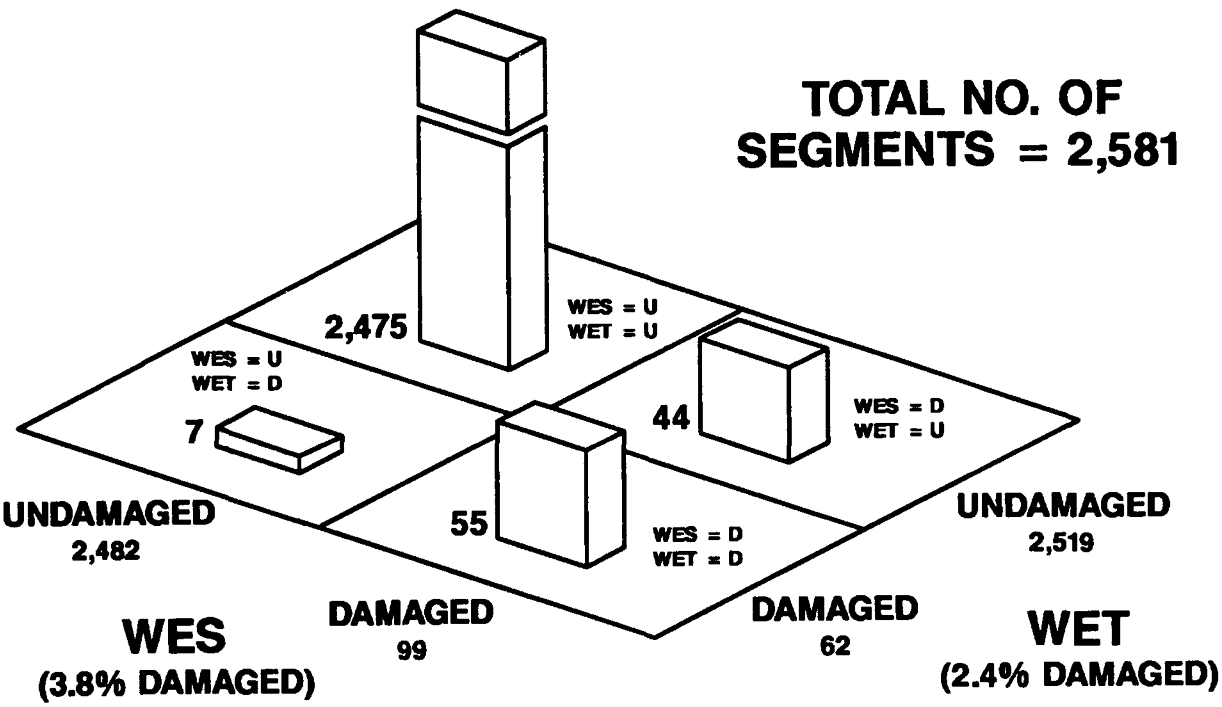


Figure 30. Comparison of WES and WET revetment damage tallies for pilot study reach, Sacramento River. Of the 99 100-ft segments classified as damaged by WES investigators in September 1989, 55 were also classified as damaged on WET field notes from April 1989. The remaining 44 were not shown as damaged on WET notes

However, the low rate of damage due to the flood made this data base of limited utility. A similar data base containing results of the 1989 inspection provided greater resolution. Interpretation of the analysis of the 198? data base involved the assumption that revetment repairs were too infrequent to influence results. This assumption appeared to be valid given the presence of almost all of the PL-99 damage over 3 years after the flood and given the presence of all of the damage sites shown on the WET field notes. Furthermore, this assumption was conservative since revetment repair would likely necessitate clearing and would increase the number of undamaged revetments without vegetation.

Comparison of 1989 damage rates for vegetated and unvegetated revetments of similar age, material, and located on banks with similar curvature revealed that vegetated banks had lower damage rates. The validity of this comparison is weakened somewhat by the low number of vegetated segments. However, when categories with fewer than five segments were excluded, similar results were obtained.

PART VI: EXPERIENCES OF OTHER CORPS DISTRICTS

Although a comprehensive survey of the experiences of other CE field offices with respect to revetment vegetation was beyond the scope of this effort, some relevant material was found during the literature review and other study components. This information is summarized below. Two types of experience were encountered: intentional use of woody vegetation on or within revetments, and maintenance policies that permitted growth of woody vegetation. Transfer or extrapolation of the experiences of other Corps Districts to the SRBPP should be done only with great care. Full consideration should be given to differences in hydraulic and geotechnical conditions and to the consequences of revetment failure.

Portland District

The Willamette River Basin encompasses 11,200 square miles in northwestern Oregon. The Willamette River is basically a high-energy gravel-bed stream in which bank erosion has been common. About 490,000 ft of riprap revetment has been constructed by the CE under special authorities. Revetment maintenance typically includes periodic removal of vegetation using manual tools (Fletcher and Davidson 1988, Forbes et al. 1976). Existing revetment vegetation species composition, density, and size vary with (a) vertical location on the riverbank, (b) maintenance history, and (c) the amount of sediment deposition within the rock (Bierly and Associates, Inc. 1980; Forbes et al. 1976). Revetments support stands of vegetation ranging from grasses and forbs to blackberry vine thickets to dense stands of mature trees (Figure 31).

The Portland District (1980) developed maintenance categories for Willamette River revetments. Each revetment was classified by an interagency committee based on engineering and adjacent land use and maintained accordingly (Figure 32 and Table 19). Some revetments were allowed to overgrow while others were required to be completely cleared. Intermediate sites were candidates for selective clearing. Revetments along the Willamette were classified based on the area protected (i.e., potential economic loss, loss of life) and the likelihood of failure. Different levels of maintenance were applied to each revetment category, and separate vegetation restrictions and encroachment standards were developed. Vegetative restrictions limited the size, density, and type of vegetation allowed to grow on the revetment.

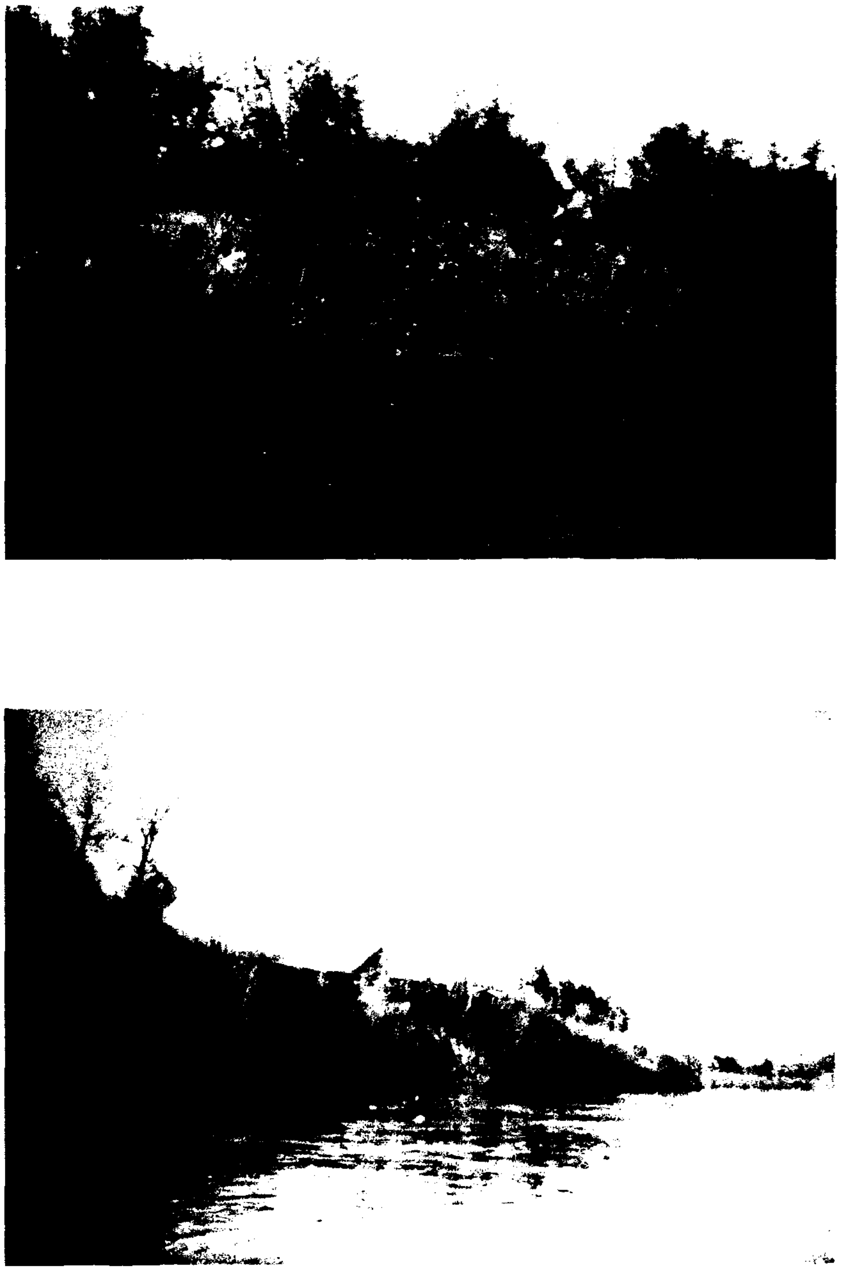
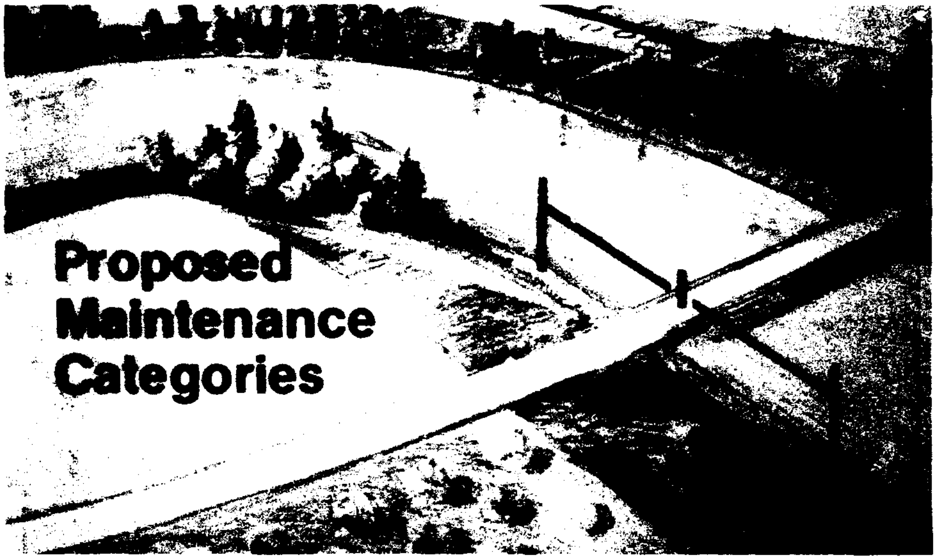


Figure 31. Vegetation observed on Willamette River revetments, November 1981



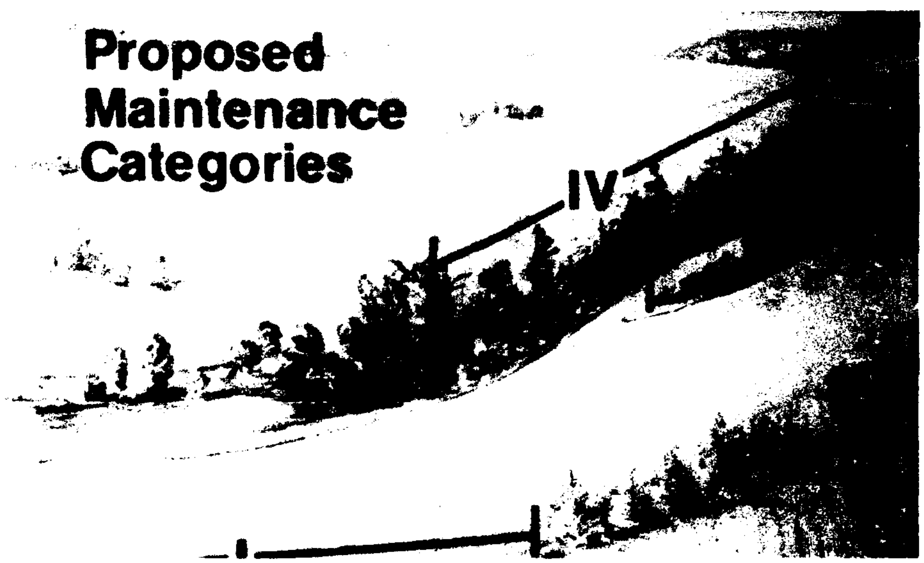


Figure 32. Maintenance categories developed for Willamette River revetments, November 1981

Table 19

Vegetation Maintenance Categories and Criteria for Existing Revetments

Category	Area Protected	Environmental Setting	Vegetative Restrictions
I (High Value--High Risk)	Critical public and private structures (bridges, roads, homes).	Revetment is under attack from the river. Structure too close (0-75 ft) for emergency repairs if revetment fails.	No vegetation to hinder inspection or impact the structural integrity of the revetment is allowed.
II (High Value--Low Risk)	Economically significant structural improvements.	Revetment is under attack. Structures are set back 150 ft or more from the crown of the revetment, giving sufficient time for emergency repairs.	(1) No vegetation that prohibits aerial inspection. (2) Sod cover of grasses and herbaceous plants, scattered clumps of low-growing (0- to 3-ft-high) shrubs and individual trees of diameter breast high (DBH) less than 6 in. and 25 ft in height.
III (Low Value--Low Risk)	Agricultural lands, parks, and other natural areas.	Revetment under attack from river.	(1) No vegetation that prohibits ground inspection. (2) Sod cover of grasses and herbaceous plants; scattered clumps of shrubs and trees DBH of less than 10 in. and 40 ft in height.
IV (Low Value--No Risk)		Revetment protected from direct attack by channel change or gravel bar formation that has occurred since construction.	None; vegetation is allowed to develop.

Revetment encroachment standards limited how close structures on adjacent land could be located. No permanent structural encroachments w· ᷊ allowed for any of the maintenance categories. If conditions changed at a revetment, the classification could be altered accordingly.

Mobile District

Maintenar·e

The Divide Section of the Tennessee-Tombigbee Waterway is a land-cut navigation canal in northwest Mississippi. Flood control is not a project purpose, and flow velocities are generally quite small. However, both banks of the canal are protected by riprap blanket overlying geotechnical filter fabric against navigation traffic-induced waves and turbulence. The USAED, Mobile (1982, 1989), has developed the following policy for vegetation growing in the riprap:

> Natural vegetation will be allowed to grow unchecked on the riprap except in "critical" areas. This includes both shallow and deep rooted woody plants. "Critical" areas have been identified as both sides of the waterway from Station 12,690+00 in the north to Station 12,240+00 to the south. These areas are defined as critical due to the depth of cut, presence of high artesian groundwater pressure, and reduced factors of safety used in slope design in this reach. Because of these factors it is imperative to maintain the integrity of the slopes and eliminate the potential damage to the filter fabric and riprap caused by root growth and/or uprooting of trees. "Critical" areas are also defined as the inside of curves. These are critical for navigational sight purposes (see paragraph 5-4). Vegetation on critical areas may be controlled by use of acceptable herbicides, mechanical cutting or a combination of the two.

During the time that this policy has been in effect, many trees with diameters exceeding 6 in. have grown in the riprap, as shown in Figure 33. Removal of the riprap around trunks of selected trees has revealed that the roots generally do not puncture the underlying filter fabric as shown in Figure 34. Although these shallow-rooted trees are easily uprooted, replacement of stone dislodged by trees uprooting is more desirable from an operations and maintenance standpoint than regular removal of saplings.*

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* Personal Communication, November 1989, Rick Saucer, USAED, Mobile, Mobile, AL.

Figure 33. Tree growing in riprap slope protection, Divide Section, Tennessee-Tombigbee Waterway, Mississippi

Figure 34. Excavation of riprap from around tree growing in slope protection, Divide Section, Tennessee-Tombigbee Waterway, Mississippi

Intentional use

Before developing the policy described above, the USAED, Mobile (1982), planted trees in selected riprap revetments on the Tennessee-Tombigbee Waterway and below Claiborne Lock and Dam on the Alabama River. The tests were conducted to determine vegetation effects on revetment. Test sites were planted with various species of trees balled in burlap. A mixture of soil and fertilizer was added to serve as a growth medium. After 16 months the two test sites had 70 and 90 percent survival rates. The site with the lower survival rate showed evidence of having experienced higher flow conditions. Trees grew in revetments by conforming to the surrounding rock. Overturning of trees by wind and subsequent scour in riprap were judged unlikely. Observations of established vegetation indicated that trees were more likely to break off near ground level rather than be overturned by wind or water.

Lower Mississippi Valley Division

Maintenance

The Lower Mississippi Valley Division allows vegetation to grow on certain revetments.* There are two cases where vegetation is prohibited on revetments. No vegetation is allowed on revetments near any type of hydraulic structure, and no vegetation is allowed on revetments in flood control channels where reduced conveyance could create problems. Vegetation is allowed to grow on most revetments, however. No studies have been conducted to determine the impacts of the revetment vegetation. However, no major revetment damage has been caused by vegetation. Revetments are considered to be intact even if covered with vegetation and sediment.

Lower Mississippi River

The Lower Mississippi River has 700 to 800 miles of revetments. Rock riprap is used primarily for upper bank protection, while articulated concrete mattress (ACM) is used primarily for lower bank protection. Navigation and flood control are project objectives. Flood control levees are typically several hundred feet to several miles distant from the main channel. Vegetation on the revetments and along the top bank reduces overbank scour during high water.* Vegetation is not removed from revetments by maintenance. A typical Lower Mississippi River revetment supporting vegetation is shown in Figure 35.

Field sampling at 25 sites indicated that Lower Mississippi revetments support an impressive amount of woody vegetation, as shown in Figure 36 (Webb and Klimas 1988). Overstory vegetation covered an average of about 30 percent of middle bank regions that were revetted with riprap. Vegetation development was more pronounced on upper than on lower banks and on sites that did not experience high velocities. Trees and large shrubs were abundant, especially in riprap. Riprap supported more vegetation and appeared to be better substrate for plant establishment, particularly for trees (Figure 37). Vines made up a major portion of the ground cover at higher bank elevations and grew better on riprap. The thickness of the riprap blanket had an important influence on vegetation establishment. Very little plant cover occurred in thick masses of riprap. Vegetation cover was greatest where sediments had filled

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* Personal Communication, 1 May 1989, Charles Elliott, Water Control Branch, US Army Engineer Division, Lower Mississippi Valley, Vicksburg, MS.

Figure 35. Catfish Point Revetment, Mississippi River, RM 574, October 1989

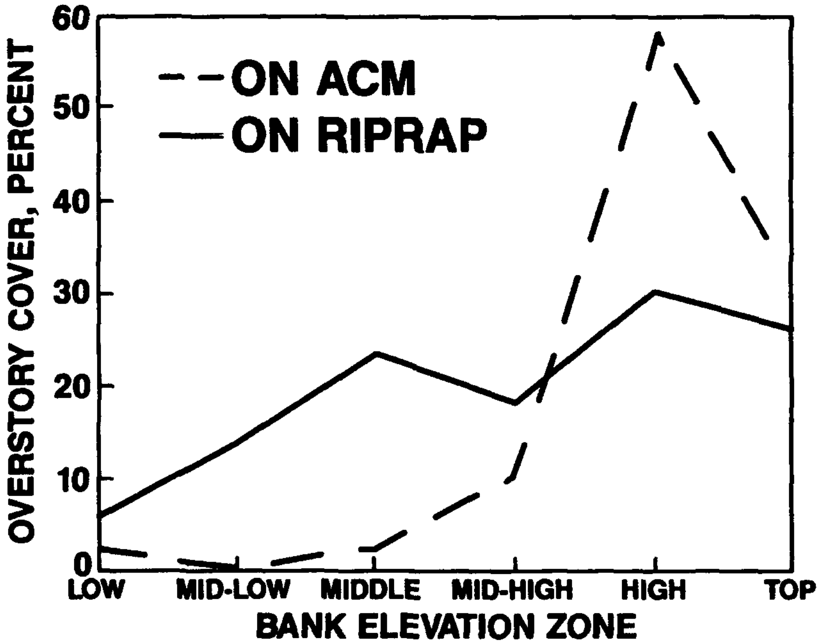

Figure 36. Percent of revetment covered by overstory on 25 Lower Mississippi River revetments (after Webb and Klimas 1988)

Figure 37. Large vegetation growing in riprap, Morameal Revetment, Red River, RM 256.1, October 1989

the interstices below the surface layer of rock and where only a single layer of rock was placed on the bank.

Red River

The Red River, Louisiana and Arkansas, is a meandering stream carrying a heavy sediment load and a wide range of flows. Levees control flood flows. Revetments have been used to control channel meandering at many locations. Some of the older revetments support well-established stands of trees. Figure 37 depicts Morameal Revetment on the Red River, which supports large trees. Most of the riprap has been covered with sediment.

Omaha District

Intentional use of
vegetation in bank protection

Twenty-eight Section 32 demonstration projects were constructed in three reaches of the Upper Missouri River between Garrison Dam and Ponca, NE. Channel widths ranged from 1,200 to 7,500 ft, channel depths to thalweg from 4 to 25 ft, and mean daily discharges from 25,800 to 35,800 cfs. Velocities within 75 ft of the bank line ranged from 0 to 6.6 fps. Erosion mechanisms were related to channel migration, large discharge fluctuations due to hydropower releases, wave and ice attack, and geotechnical factors (USACE 1981). Two of the demonstrated bank protection methods that featured intentional use of vegetation included composite and reinforced revetment.

Composite revetment

Vegetation proved to be effective at stopping erosion in upper bank portions of composite revetment at Missouri River Section 32 demonstration sites (USACE 1981, Appendix E). The composite revetments utilized different protection materials for various streambank zones, the limits of which were determined by flow durations (Allen 1978), as shown in Figure 38. The freeboard zone, that portion of bank above the normal high-water elevation, often incorporated vegetation in riprap or other materials such as gravel, clay, filter fabric, and cellular concrete blocks. Vegetation was also used alone as upper bank protection, depending on site conditions. All of the experimental upper bank treatments were effective at stopping erosion. The results showed that although composite revetments are effective in a range of situations, they cannot be used where channel velocities and other conditions

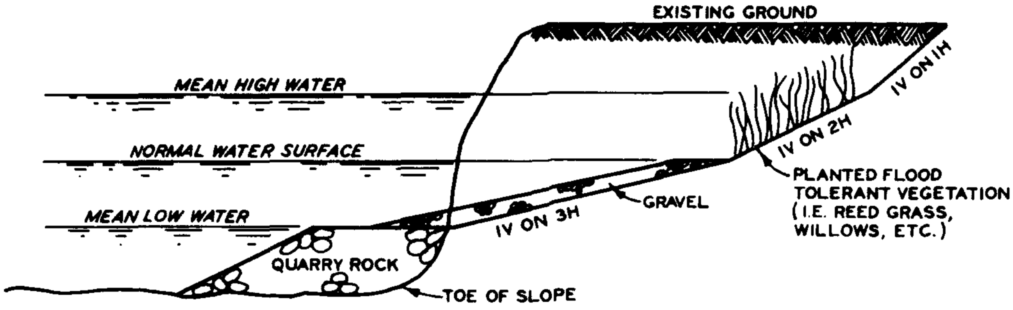

Figure 38. Typical composite revetment design

exceed the erosion resistance capabilities of the materials used in the splash and freeboard zones.

Reinforced revetment

Reinforced revetment was demonstrated at 23 of the 28 Missouri River Section 32 sites (USACE 1981, Appendix E). Reinforced revetment consists of stone placed parallel to the bank line along the toe or slightly riverward and tied back landward into the bank at intervals (Figure 39). The areas between tiebacks were graded, backfilled, and seeded. Although plants were not seeded directly in the riprap, vegetation eventually established by natural invasion (Figure 40). The areas excavated for tiebacks gradually reverted to preconstruction conditions. Reinforced revetment proved effective in stopping erosion at the Missouri River Section 32 Program demonstration sites.

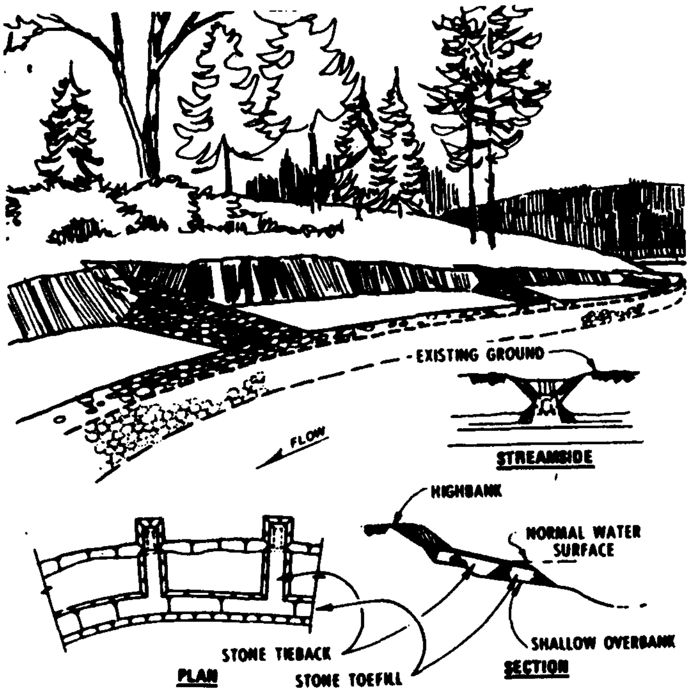

Figure 39. Typical reinforced revetment design

a. Reinforced revetment construction showing tiebacks

b. Vegetation established between tiebacks

Figure 40. Vegetation growth within reinforced revetment on Missouri River

PART VII: SUMMARY AND RECOMMENDATIONS

Summary

Federal and CE regulations specifically address removal of woody vegetation from levee slopes and flood control channels, but vegetation on revetted banks that are not part of a levee is not specifically prohibited. However, current CE maintenance standards as applied to the SRFCP prohibit woody vegetation on revetments. The main reasons that vegetation is undesirable on revetment include potential reduction of channel conveyance, potential impairment of revetment visibility for inspection, and potential reduced revetment durability. Only revetment durability was addressed in this study.

Literature review revealed little information regarding effects of vegetation on revetment durability. The propensity of riverbank revetments to support woody vegetation and the habitat value of these plant communities was noted by several investigators. Although incorporation of plant materials in revetments is not standard engineering practice, several sources, including the USACE (1981), indicate that living woody vegetation growing through revetments adds strength. Accordingly, revetment designs that include planted or volunteer vegetation have been widely proposed and tested. Several CE field offices permit limited woody vegetation in revetments at particular projects.

Although the 1986 flood approached or exceeded record and design discharge magnitudes for much of the SRBPP reach of the Sacramento River, documented revetment damage due to the flood was extremely limited. A review of Sacramento District files for emergency assistance requests under PL 84-99 revealed only six damaged sites. Five of the six revetment damage sites were located between RM 84.5 and 99.5; four of the five were riprap revetments on convex banks; and only one of the five was damaged severely enough to be repaired by 1989.

The Sacramento River reach between the Fremont and Tisdale Weirs (RM 84.5 to 119) has no major inflows or outflows during floods. Since this reach contained five of the six documented 1986 revetment damage sites, a pilot study was conducted using this reach as the study area. Interviews with local interests and field inspections indicated that there were no additional major 1986 flood revetment damage locations in the pilot reach. Study of aerial photographs, inspection records, and revetment construction dates showed that none of the damaged revetments supported significant woody vegetation at the time of the flood.

Visual inspection of the pilot study reach revetments from a boat in September 1989 revealed additional (but slight) revetment damage primarily to older cobble revetments. The observed damage appeared to be related to geotechnical factors or toe failure; revetment function did not seem to be impaired. Damage rates for revetments supporting woody vegetation tended to be lower than for revetments of the same age and located on banks of similar curvature but without woody vegetation.

About 70 percent of the bank line of the inspected reach was revetted. About two thirds of the revetment was cobble, and about one third was rock riprap. Seven percent of the revetted bank line supported some type of woody vegetation.

Recommendations

General

If the maintenance guidelines in the Standard Operation and Maintenance Manual for the SRFCP are revised, revetment vegetation should be specifically addressed in detail.

Discussions should be initiated among the agencies involved (CE, DWR, local interests) to determine why information recorded by inspectors on DWR Form 167 does not accurately reflect the amount of woody vegetation on revetments.

Phase 2 studies

The study described above evaluated methods of examining vegetated revetments on the Sacramento River. Relationships between vegetation and 1986 flood revetment damages as well as relationships between vegetation and damages that were discovered by 1989 field inspections were investigated. The successful use of aerial photography and field surveys in determining vegetation sizes in the pilot study reach showed that these techniques could be applied to other reaches.

Additional investigation of the 1986 vegetation conditions on Sacramento River revetments or the single 1986 documented damage site outside the pilot reach (187.1L) would probably yield very little information other than quantifying the amount of woody vegetation on revetments at the time of the flood.

Therefore, the approach of future studies should be modified to relate to existing revetment vegetation instead of historical damage.

Further study of the effects of vegetation on SRFCP revetment durability and resultant refinement of maintenance guidelines should be done on a reach-by-reach basis. Reaches should be defined based on major hydrologic, hydraulic, and geomorphologic factors. Effects of changes in maintenance policy on sediment routing and on the division of flood flows between the river and the bypasses should be considered since safety issues may be involved.

Additional studies could be conducted to increase the amount of data on vegetated revetments. One study would be a field inspection of all revetments in the SRBPP. This inspection would note the size of the vegetation on individual SRBPP revetments. The vegetation would be marked on Sacramento District aerial photos that have the revetment locations noted. Revetment damage would also be noted. (Many current sites of revetment damage on the Sacramento River have been located during various District efforts, such as geomorphic and geotechnical studies.) The vegetation data and the damage data would serve as baseline data for future studies. Follow-up studies could be conducted either periodically or after major flood events. Either the entire project could be monitored, or specific revetments (such as existing demonstration sites) could be selected based on the age, size, and type of vegetation and monitored in great detail.

The comprehensive survey of SRBPP revetment damage and vegetation would provide a basis for the following tasks:

(1) Identification of general reaches where maintenance standards could be relaxed or modified, and

(2) Development of criteria for identifying specific existing or proposed revetment sites within the general reaches where maintenance standards could be relaxed. These criteria will include consideration of project operation impacts, hazards of revetment failure, geomorphic and geotechnical considerations, and channel hydraulics.

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APPENDIX A: SURVEY OF LOCAL INTERESTS, SAMPLE LETTER AND RESPONSES

Environmental Laboratory

Mr. Glen Hiatt, President
Reclamation District 1500
Star Route
Knights Landing, California 95645

Dear Mr. Hiatt:

The U.S. Army Engineer Waterways Experiment Station is conducting a study of revetment durability for the Sacramento District of the Corps of Engineers. This study deals with the performance of revetments located on the banks of the Sacramento River between the Fremont and Tisdale Weirs (river miles 82 to 119) during the 1986 flood. We are interested in identifying revetment sites that were damaged or that failed during the 1986 flood. Please help us by taking a few moments to complete the enclosed form and mail it in the postage-paid envelope provided.

If you have any questions, please contact Dr. F. Douglas Shields, Jr., at 601/634-3707. Thank your for your cooperation.

Sincerely,

Jack R. Stephens
Lieutenant Colonel, Corps of Engineers
Acting Commander and Director

Enclosures

Copy Furnished:

Mr. Ed Sing, USAE, Sacramento

LIST OF ADDRESSEES:

Mr. Emery B. Poundstone, President
Reclamation District 108 P. O. Box 887
Colusa, CA 95932

Mr. Glenn Hiatt, President
Reclamation District 1500
Star Route
Knights Landing, CA 95645

Mr. Harry A. Helin, Jr., President
Reclamation District 787
Knights Landing, CA 95645

Mr. James Balsdon, President
Sacramento River West Side Levee District
P. O. Box 76
Grimes, CA 95950

Mr. Lloyd Roberts, Director of Public Works
Yolo County Service Area No. 6
292 W. Beamer St.
Woodland, CA 95695

PILOT PHASE SURVEY OF LOCAL INTERESTS--1986 FLOOD REVETMENT DAMAGES

1. Reclamation District: 1500

2. Person completing form:

NAME: Gordon Bailey

TITLE: Manager

ADDRESS: P.O. BOX 96

Robbins, Ca. 95676

TELEPHONE NO. 916-738-4423

3. Can you identify a revetted bank on the Sacramento River that was damaged or failed during the 1986 flood?

XXX YES ______ NO

4. If yes, what documentation exists?

XXX DISTRICT RECORDS OR FILES

______ PHOTOGRAPHS

______ PERSONAL RECOLLECTION
(Please provide name and phone number for contact)

5. Approximate locations (river mile, right or left bank) of damaged site(s):

94.0 LT

PILOT PHASE SURVEY OF LOCAL INTERESTS--1986 FLOOD REVETMENT DAMAGES

1. ~~Reclamation District~~: Sacramento River West Side Levee Dist.

2. Person completing form:

NAME: Kenneth E. Lerch

TITLE: District Engineer

ADDRESS: P.O. Box 828

Woodland, CA 95695

TELEPHONE NO. 916-662-1755

3. Can you identify a revetted bank on the Sacramento River that was damaged or failed during the 1986 flood?

X YES ______ NO

4. If yes, what documentation exists?

X DISTRICT RECORDS OR FILES

______ PHOTOGRAPHS

X PERSONAL RECOLLECTION
(Please provide name and phone number for contact)

Self.

5. Approximate locations (river mile, right or left bank) of damaged site(s):

Dist. river mile 9.50 (C of E 99.2R.)

COMMISSIONERS
JAMES H. BALSDON, PRESIDENT
GARY W. DRIVER
LEO STEIDLMAYER
C.R. FARNSWORTH
HARRY A. HELM, JR.

SECRETARY-MANAGER
DAVID P. GRANICHER
P.O. BOX 86
GRIMES, CALIFORNIA
95950

SACRAMENTO RIVER WEST SIDE LEVEE DISTRICT

COLUSA AND YOLO COUNTIES
CALIFORNIA

ATTORNEYS
DOWNEY, BRAND, SEYMOUR AND ROHWER
SACRAMENTO, CALIFORNIA

ENGINEERS
LAUGENOUR AND MEIKLE
P.O. BOX 828
WOODLAND, CALIFORNIA
95695

RECEIVED
APR 14 1986
LAUGENOUR & MEIKLE
WOODLAND, CA 95695

April 10, 1986

Raymond Barsch, General Manager
The Reclamation Board
1416 Ninth Street, Room 455-6
Sacramento, California 95814

Dear Mr. Barsch,

The District levee sustained a certain amount of damage during the recent high water. The river has dropped enough now to get a better look at some of these trouble areas.

At mile 20.30 there is wave wash which the District, in the past, has repaired.

The levee at mile 22.00 ± has damage. Further, the levee section in this area is really not of sufficient mass to be safe for long periods of high water.

The rock revetment site at mile 9.50 which was completed last year in Unit 38A is damaged. A large section of the rock has slipped off of the slope.

These areas all should be considered eligible for some assistance from the Corps of Engineers. I request that we have a joint inspection to look over these areas.

Sincerely,
SACRAMENTO RIVER WEST SIDE LEVEE DISTRICT

David P. Granicher, Secretary-Manager

DPG:dd
cc J. D. Countryman - Corps of Engineers
Kenneth Lerch - Laugenour & Meikle

RECEIVED
APR 16 1986
LAUGENOUR & MEIKLE
WOODLAND, CA

REGULAR MEETING OF BOARD OF COMMISSIONERS
OF
SACRAMENTO RIVER WEST SIDE LEVEE DISTRICT

April 9, 1986

The regular meeting of the Board of Commissioners of the Sacramento River West Side Levee District was held at the Reclamation District No.108 Headquarters, Colusa County, California, on Wednesday, April 9, 1986 at 9:30 A.M.

Commissioners present were James Balsdon, Gary Driver, Harry A. Hellin, Jr. and C. R. Farnsworth. Also present were Engineer Kenneth Lerch, Attorney George Basye, Secretary-Manager David P. Granicher, Emery Poundstone, Jack Wallace and Peter Spahr.

President Balsdon called the meeting to order at 9:30 A.M.

The minutes of the regular meeting of February 12, 1986 were approved as submitted.

Maintenance Estimate 86/4 was presented along with the bi-monthly Report of Investments. It was moved by Commissioner Driver, seconded by Commissioner Farnsworth and carried that the reports be approved and ordered filed and warrants were directed to be delivered to the persons and in the respective amounts set out therein and in the aggregate sum of $18,818.94.

A letter to the Board from Commissioner Leo Steidlmayer tendering his resignation was discussed. Attorney Basye reviewed the process of replacing members of the Board of Commissioners. The resignation was accepted with regret.

The Attorney explained a piece of legislation which would give reclamation districts the authority to charge up to $25.00 per parcel for an annual assessment levy. An amendment to this bill which would authorize this District to be included in such a provision has been proposed. Manager Granicher commented that the current $2.00 maximum for certain parcels barely pays for the cost of billing and collection. It was moved by Commissioner Hellin, seconded by commissioner Farnsworth and carried to support this bill with amendments and directed the Manager to express this support to the legislature.

Engineer Lerch reported that unit 38B will include eight sites with approximately 6,400 linear feet of work on the District levee. The contract for the work should be awarded within a week or so and it is possible that an additional site may be added. He reported that funds which had been budgeted for the Tisdale Weir channel have been removed from the State budget and suggested that the California Central Valleys Flood Control Association take a more active part in following projects through planning and the budgetary process.

The Manager reported that during the high water, damage occured to a rock revetment project in Unit 38A which was completed last year, that a certain amount of wave wash damage had occured, and that an area near Steiner Bend and one near Grimes appeared to present considerable hazard to the integrity of the levee system. The concensus of the Board was that these were serious problems and directed the Manager to communicate with the Reclamation Board and the Corps of Engineers about these potentially troublesome areas.

There being no further business, the meeting was adjourned.

Respectfully submitted,

David P. Granicher, Secretary

APPENDIX B: LIST OF AERIAL PHOTOGRAPHS USED IN THIS STUDY

Photo Date	Photo Number	Nominal Scale	Size in.	Source*
17-Mar-84	WAC-84C-1-29	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-30	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-31	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-32	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-33	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-34	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-35	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-36	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-37	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-38	1:31,680	9	WAC
17-Mar-84	WAC-84C-1-39	1:31,680	9	WAC
18-Mar-84	WAC-84C-3-66	1:31,680	9	WAC
18-Mar-84	WAC-84C-3-67	1:31,680	9	WAC
18-Mar-84	WAC-84C-3-68	1:31,680	9	WAC
19-Mar-84	WAC-84C-5-34	1:31,680	9	WAC
19-Mar-84	WAC-84C-5-35	1:31,680	9	WAC
19-Mar-84	WAC-84C-5-36	1:31,680	9	WAC
19-Mar-84	WAC-84C-5-37	1:31,680	9	WAC
19-Mar-84	WAC-84C-5-38	1:31,680	9	WAC
19-Mar-84	WAC-84C-5-39	1:31,680	9	WAC
20-Mar-84	WAC-84C-5-112	1:31,680	9	WAC
20-Mar-84	WAC-84C-5-113	1:31,680	9	WAC
20-Mar-84	WAC-84C-5-114	1:31,680	9	WAC
20-Mar-84	WR-ASJ-114	1:24,000	9	DWR
20-Mar-84	WR-ASJ-119	1:24,000	9	DWR
20-Mar-84	WR-ASJ-120	1:24,000	9	DWR
20-Mar-84	WR-ASJ-121	1:24,000	9	DWR
20-Mar-84	WR-ASJ-122	1:24,000	9	DWR
20-Mar-84	WR-ASJ-123	1:24,000	9	DWR
20-Mar-84	WR-ASJ-124	1:24,000	9	DWR
20-Mar-84	WR-ASJ-125	1:24,000	9	DWR
20-Mar-84	WR-ASJ-126	1:24,000	9	DWR
20-Mar-84	WR-ASJ-127	1:24,000	9	DWR
20-Mar-84	WR-ASJ-128	1:24,000	9	DWR
20-Mar-84	WR-ASJ-129	1:24,000	9	DWR
20-Mar-84	WR-ASJ-130	1:24,000	9	DWR
20-Mar-84	WR-ASJ-131	1:24,000	9	DWR
20-Mar-84	WR-ASJ-132	1:24,000	9	DWR
20-Mar-84	WR-ASJ-133	1:24,000	9	DWR
20-Mar-84	WR-ASJ-134	1:24,000	9	DWR
20-Mar-84	WR-ASJ-135	1:24,000	9	DWR
20-Mar-84	WR-ASJ-136	1:24,000	9	DWR
20-Mar-84	WR-ASJ-137	1:24,000	9	DWR
20-Mar-84	WR-ASJ-138	1:24,000	9	DWR
20-Mar-84	WR-ASJ-139	1:24,000	9	DWR

* WAC = Western Aerial Contractors
DWR = California Department of Water Resources
ASCS = Agricultural Stabilization and Conservation Service
USCE = Sacramento District, US Army Corps of Engineers
NASA = National Aeronautics and Space Adminstration

Photo Date	Photo Number	Nominal Scale	Size in.	Source
20-Mar-84	WR-ASJ-140	1:24,000	9	DWR
20-Mar-84	WR-ASJ-141	1:24,000	9	DWR
20-Mar-84	WR-ASJ-142	1:24,000	9	DWR
22-Mar-84	SA-10	1:54,000	9	USCE
22-Mar-84	SA-11	1:54,000	9	USCE
22-Mar-84	SA-12	1:54,000	9	USCE
22-Mar-84	SA-13	1:54,000	9	USCE
22-Mar-84	SA-14	1:54,000	9	USCE
22-Mar-84	SA-15	1:54,000	9	USCE
22-Mar-84	SA-16	1:54,000	9	USCE
22-Mar-84	SA-17	1:54,000	9	USCE
22-Mar-84	SA-18	1:54,000	9	USCE
08-Jun-84	NHAP 125-208	1:58,000	9	ASCS
08-Jun-84	NHAP 125-208	--	38	ASCS
08-Jun-84	NHAP 125-209	1:58,000	9	ASCS
08-Jun-84	NHAP 125-209	--	38	ASCS
08-Jun-84	NHAP 125-210	1:58,000	9	ASCS
08-Jun-84	NHAP 125-210	--	38	ASCS
08-Jun-84	NHAP 125-211	1:58,000	9	ASCS
08-Jun-84	NHAP 125-211	--	38	ASCS
08-Jun-84	NHAP 127-23	1:58,000	9	ASCS
08-Jun-84	NHAP 127-23	--	38	ASCS
08-Jun-84	NHAP 127-24	1:58,000	9	ASCS
08-Jun-84	NHAP 127-25	--	38	ASCS
08-Jun-84	NHAP 127-26	--	38	ASCS
29-Jun-87	NAPP 515-138	1:40,000	9	ASCS
29-Jun-87	NAPP 515-138	--	38	ASCS
29-Jun-87	NAPP 515-139	1:40,000	9	ASCS
29-Jun-87	NAPP 515-139	--	38	ASCS
29-Jun-87	NAPP 515-140	1:40,000	9	ASCS
29-Jun-87	NAPP 515-140	--	38	ASCS
29-Jun-87	NAPP 515-141	--	38	ASCS
30-Jun-87	NAPP 516-28	1:40,000	9	ASCS
30-Jun-87	NAPP 516-30	--	38	ASCS
30-Jun-87	NAPP 516-67	--	38	ASCS
30-Jun-87	NAPP 516-68	--	38	ASCS
30-Jun-87	NAPP 516-29	1:40,000	9	ASCS
30-Jun-87	NAPP 524-152	--	38	ASCS
13-Jul-87	NAPP 524-153	1:40,000	9	ASCS
13-Jul-87	NAPP 524-153	--	38	ASCS
13-Jul-87	NAPP 524-154	1:40,000	9	ASCS
13-Jul-87	NAPP 524-154	--	38	ASCS
28-Jun-85	NASA 856	1:62,000	20	NASA
28-Jun-85	NASA 857	1:62,000	20	NASA
28-Jun-85	NASA 858	1:62,000	20	NASA
28-Jun-85	NASA 859	1:62,000	20	NASA
28-Jun-85	NASA 860	1:62,000	20	NASA
28-Jun-85	NASA 861	1:62,000	20	NASA
28-Jun-85	NASA 862	1:62,000	20	NASA
28-Jun-85	NASA 667	1:62,000	20	NASA
28-Jun-85	NASA 668	1:62,000	20	NASA

Photo Date	Photo Number	Nominal Scale	Size in.	Source
28-Jun-85	NASA 669	1:62,000	20	NASA
28-Jun-85	NASA 670	1:62,000	20	NASA
28-Jun-85	NASA 671	1:62,000	20	NASA
28-Jun-85	NASA 672	1:62,000	20	NASA
28-Jun-85	NASA 673	1:62,000	20	NASA
28-Jun-85	NASA 674	1:62,000	20	NASA
27-Jul-85	NASA 582	1:62,000	20	NASA
27-Jul-85	NASA 583	1:62,000	20	NASA
27-Jul-85	NASA 584	1:62,000	20	NASA
27-Jul-85	NASA 585	1:62,000	20	NASA
27-Jul-85	NASA 586	1:62,000	20	NASA
27-Jul-85	NASA 587	1:62,000	20	NASA

APPENDIX C: DWR INSPECTION RECORDS, PILOT STUDY REACH, 1985 AND 1986

THE RESOURCES AGENCY

FLOOD CONTROL PROJECT MAINTENANCE

LEVEE INSPECTION

DISTRICT OR AREA R. D. No. 1500 DATE OF INSPECTION: SPRING 3/27/85 FALL 9/23/85

UNIT NO. 1 LENGTH 33.58 MILES LEVEE L.B. Sacto. River SHEET ___ OF ___ SHEETS

ITEM	INSPECTION	MAINTENANCE AND/OR REPAIRS ARE REQUIRED AT THE FOLLOWING LEVEE MILES (FROM) (TO)										TOTAL
CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	32.74 / 32.75	—	Wild	Berrys	—	—	—	—	—	—	0.01
	SPRING W.S.	2.56 / 2.57	3.32 / 3.33	Wild	Berrys	—	—	—	—	—	—	0.02
	FALL L.S.	32.74 / 32.75	33.35	Wild	Berrys	—	—	—	—	—	—	0.01
	FALL W.S.	2.56 / 2.57	3.32 / 3.33	Wild	Berrys	—	—	—	—	—	—	0.02
(CONT.) CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	—	—	—	—	—	—	—	—	—	—	
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	—	—	—	—	—	—	—	—	—	—	
CONTROL GROWTH IN ROCK REVETMENT	SPRING 26.52	15.77 / 15.35	20.88 / 20.90	22.95 / 22.96	24.05 / 24.07	24.99 / 24.90	25.05 / 25.06	Trees	& Berrys		—	0.16
	FALL	15.77 / 15.85	20.89 / 20.90	22.95 / 22.96	24.05 / 24.07	24.88 / 24.89	25.05 / 25.06	31.74 / 31.75	Trees, & Bamboo	Berrys	—	0.16
EXTERMINATE RODENTS AND FILL BURROWS	SPRING L.S.	0.29	5.18	8.21	8.97 / 9.03	12.59	21.27	26.89	32.74	And	—	8 Sites
	SPRING W.S.	9.17	21.55	—	—	—	—	—	Where	Needed	—	2 Sites
	FALL L.S.	0.11	3.74	7.41 / 7.46	8.47	8.96 / 9.02	12.65	29.69	31.40	32.73 / 32.76	And	9 Sites
	FALL W.S.	0.34	—	—	—	—	—	—	Where	Needed	—	1 Site
REPAIR CROWN ROADWAY	SPRING	2.50 / 2.75	14.40 / 14.85	19.60 / 19.70	20.40 / 20.70	23.95 / 24.55	26.30 / 27.30	29.05 / 29.95	31.85 / 32.[illegible]	33.00 / 33.40	Weeds	4.15
	FALL	—	—	—	—	—	—	—	—	—	—	
CONTROL LIVESTOCK PASTURING	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
REPAIR GATES	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
UNAUTHORIZED ENCROACHMENTS	SPRING	0.53P / Berm	1.31P / 1.34G	1.39E / 1.41G	3.17G	5.17D	6.57F / Berm	7.63P / Berm	8.69P / Berm	8.83F	8.96F / 8.98	Contd.
	FALL	1.31P / 1.34G	1.39E / 1.41G	3.17G	3.56F / Tractor	5.17D	5.39G / 5.40D	7.63P / Berm	8.69P / Berm	8.83F	8.96F / 8.98	Contd.
PIPES ABANDONED OR IN POOR CONDITION	SPRING +F.P.	—	—	—	—	—	—	—	—	—	—	
	SPRING −F.P.	6.97	24.60	25.80	—	—	—	—	—	—	—	3 Sites
	FALL +F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL −F.P.	6.97	24.60	25.80	—	—	—	—	—	—	—	3 Sites
EROSION (ON BANK, OR SLOPE)	SPRING	0.16 / 0.34	5.69 / 5.73	9.88 / 9.91	11.93 / 11.96	12.64 / 12.66	—	—	—	—	—	5 Sites
	FALL	0.16 / 0.34	11.93 / 11.96	12.64 / 12.66	—	—	—	—	—	—	—	3 Sites
PROPOSED USCE ROCK SITES UNIT 3B	SPRING	9.47 / 9.94	12.65 / 12.73	16.56 / 16.73	20.55 / 20.77	—	—	—	—	—	—	4 Sites
	FALL	16.56 / 16.73	20.55 / 20.77	—	—	—	—	—	—	—	—	2 Sites
UNAUTHORIZED ENCROACHMENTS	SPRING	11.90P / Berm	14.32E / 14.44C	15.34H / Berm	15.91E / 15.95	17.43F / Trunks	21.52F / Pipes	25.86P / Tree	33.34F / 33.36G	—	—	18 Sites
	FALL	14.32E / 14.44P	15.34P / Berm	15.91E / 15.93	16.93F / Berm	21.53F / Pipes	25.26F / Tree	33.34F / 33.36G	—	—	—	17 Sites

REMARKS — SPRING: Spray or remove the wild growth from the levee slopes and/or the rock revetment. Mow or burn the levee slopes during the summer months. Sterilize the crown roadway for weed control. Remove the unauthorized encroachments listed above. Walnut trees within easement at L.M. 7.30 (22) & 8.25 (4)

REMARKS — FALL: ~~The levee slopes were burned, where practical. A very good levee maintenance program is in effect. Walnut trees (26) owned by Mr. J. Driver are still encroached within the State's easement at L.M. 7.30 and 8.25. Two new rock revetment sites were constructed by the USCE.~~

INSPECTED BY R. Quinn APPROVED BY [signature] DATE 11/12/85

REVIEWED AND COPY RECEIVED BY [signature] DATE ______

L.S. LANDSIDE W.S. WATERSIDE +F.P. ABOVE FLOOD PLANE −F.P. BELOW FLOOD PLANE

ENCROACHMENT SYMBOLS:

A - SIGNS C - LANDSCAPING E - EQUIPMENT OR MATERIAL G - GARBAGE OR TRASH T - TANK

B - BUILDINGS D - STAIRWAYS F - FENCES H - POLES P - PUMPINGS

DWR 107 (REV 7/80)

District or Area R.D. No. 1500 - 1

THE RESOURCES AGENCY

FLOOD CONTROL PROJECT MAINTENANCE
LEVEE INSPECTION

DISTRICT OR AREA S.R.W.S.L.D. DATE OF INSPECTION: SPRING 4/23/85 FALL 10/30/85

UNIT NO. ______ LENGTH 50.24 MILES LEVEE 2 D Sacramento River SHEET ___ OF ___ SHEETS

ITEM	INSPECTION	MAINTENANCE AND/OR REPAIRS ARE REQUIRED AT THE FOLLOWING LEVEE MILES (FROM) (TO)										TOTAL
CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	6.02	8.72 / 9.73	9.80 / 8.85	34.71 / 34.75	—	—	—	—	—	—	1.10
	SPRING W.S.	0.12 / 0.26	6.47 / 6.49	6.58 / 6.60	11.94 / 12.00	12.49 / 12.57	12.61 / 12.89	13.33 / 13.56	26.22 / 26.23	26.25 / 26.27	27.26	Contd. below
	FALL L.S.	3.48 / 3.49	35.47 / 35.49	—	—	—	—	—	—	—	—	2.23
	FALL W.S.	1.13 / 1.16	1.29 / 1.33	3.15 / 3.20	4.03 / 4.08	4.45 / 4.54	4.58 / 4.60	4.63 / 4.65	4.75 / 4.81	12.30 / 12.34	12.52 / 12.92	Contd.
(CONT.) CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	27.56 / 27.58	27.71 / 27.74	35.62 / 35.66	35.93 / 35.96	37.87 / 35.89	37.93 / 37.75	33.11 / 38.14	—	—	—	1.11
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	13.37 / 13.60	17.80 / 17.84	19.20 / 19.26	23.45 / 23.50	25.10 / 25.15	26.21 / 26.32	26.36 / 26.51	27.60 / 27.80	34.69 / 34.99	35.33 / 35.38	Contd.
CONTROL GROWTH IN ROCK REVETMENT	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
EXTERMINATE RODENTS AND FILL BURROWS	SPRING L.S.	5.10	39.20	39.34	42.32	42.35	—	—	—	—	—	5 Sites
	SPRING W.S.	—	—	—	—	—	—	—	—	—	—	
	FALL L.S.	3.33	6.00 / 6.05	15.30 / 15.40	20.20	34.75	—	—	—	—	—	5 Sites
	FALL W.S.	—	—	—	—	—	—	—	—	—	—	
REPAIR CROWN ROADWAY	SPRING	29.43 / 35.53	Sterilize the crown roadway for weed control as needed.									3.10
	FALL	—	—	—	—	—	—	—	—	—	—	
CONTROL LIVESTOCK PASTURING	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
REPAIR GATES	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
UNAUTHORIZED ENCROACHMENTS	SPRING W/S	10.24 / 10.31P	10.89 W/L S	L/S 27.32 / 27.90P	W/S 31.78 / 31.81F	—	—	—	—	—	—	4 Sites
	FALL	2.51 / 2.56	2.56 / D	10.25 / 10.31F	12.79 / D	16.90 / G	19.20 / 19.22	19.34 / G	23.10 / C	27.29 / Stumps	35.36 / Tree	10 Sites
PIPES ABANDONED OR IN POOR CONDITION	SPRING +F.P.	—	—	—	—	—	—	—	—	—	—	
	SPRING -F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL +F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL -F.P.	—	—	—	—	—	—	—	—	—	—	
EROSION ON BANK OR SLOPE	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
TRIM TREES	SPRING W/S	0.74 / 0.77	1.06 / 1.08	1.11 / 1.13	1.19	1.32 / 1.41	5.94 / 5.96	6.09	—	—	—	7 Sites
	FALL	0.74 / 0.77	0.98 / 1.01	1.11 / 1.13	1.19 / 1.21	1.32 / 1.41	2.10 / 2.12	4.69 / 4.72	9.95 / 10.25	19.73 / 19.75	27.28 / 27.29	10 Sites
CONTROL WILD GROWTH	SPRING	—	—	—	—	—	—	—	—	—	—	
	W/S FALL	35.44 / 35.50	35.59 / 35.77	35.85 / 35.86	—	—	—	—	—	—	—	2.21

REMARKS — SPRING

Mow or burn the levee slopes during the summer months.

9.03 - 9.27 Prune cuttings along riverbank.

Good maintenance program.

REMARKS — FALL

Good program in effect.

*Pipes.

INSPECTED BY A. Vasquez APPROVED BY Gene S. Imos DATE 11/27/85

REVIEWED AND COPY RECEIVED BY ____ DATE ____

L.S. LANDSIDE W.S. WATERSIDE +F.P. ABOVE FLOOD PLANE -F.P. BELOW FLOOD PLANE

ENCROACHMENT SYMBOLS:

A - SIGNS C - LANDSCAPING E - EQUIPMENT OR MATERIAL G - GARBAGE OR TRASH T - TANK

B - BUILDINGS D - STAIRWAYS F - FENCES H - POLES P - PLANTINGS

DWR 107 (REV 7/80)

District or Area S.R.W.S.L.D.

F-1

FLOOD CONTROL PROJECT MAINTENANCE
LEVEE INSPECTION

DISTRICT OR AREA Yolo County Service Area #6 DATE OF INSPECTION: SPRING 4/22/85 FALL 12/10/85

UNIT NO. ______ LENGTH 5.97 MILES LEVEE R.B. Sacramento River SHEET ___ OF ___ SHEETS

ITEM	INSPECTION	MAINTENANCE AND/OR REPAIRS ARE REQUIRED AT THE FOLLOWING LEVEE MILES (FROM) / (TO)										TOTAL
CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	2.07	—	—	—	—	—	—	—	—	—	1 Site
	SPRING W.S.	1.32 / 1.36	1.88 / 1.99	1.93 / 1.95	1.99	2.07	2.10	2.17	2.20 / 2.27	2.2[illegible] / [illegible].31	[illegible].34 / [illegible]	Contd.
	FALL L.S.	2.74	—	—	—	—	—	—	—	—	—	1 Site
	FALL W.S.	[illegible]	1.95 / 1.97	2.01	2.12	[illegible]	2.40 / 2.[illegible]	2.95 / [illegible]	5.2[illegible] / [illegible]	—	—	2.43
(CONT.) CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	2.16 / 2.66	2.72 / 2.85	2.90 / 2.93	2.95 / 2.96	5.02 / 5.06	5.75 / 5.38	—	—	—	—	0.74 / 7.9[illegible]
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	—	—	—	—	—	—	—	—	—	—	
CONTROL GROWTH IN ROCK REVETMENT	SPRING 2.65	0.62 / 0.66	2.35 / 2.45	2.92 / 3.23	3.34 / 3.45	3.98 / 3.98	—	5.52 / 5.75	—	—	—	0.89
	FALL	0.40 / 0.43	0.62 / 0.66	2.35 / 2.45	2.92 / 3.23	3.34 / 3.45	3.89 / 3.98	4.34 / 4.37	5.52 / 5.75	—	—	0.95
EXTERMINATE RODENTS AND FILL BURROWS	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	—	—	—	—	—	—	—	—	—	—	
	FALL L.S.	0.05	2.90	3.02	—	—	—	—	—	—	—	3 Sites
	FALL W.S.	0.72 / 0.73	—	—	—	—	—	—	—	—	—	1 Site
REPAIR CROWN ROADWAY	SPRING	2.95 / 3.25	Spray	Crown	—	—	—	—	—	—	—	.30
	FALL	—	—	—	—	—	—	—	—	—	—	
CONTROL LIVESTOCK PASTURING	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
REPAIR GATES	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
UNAUTHORIZED ENCROACHMENTS	SPRING	2.57 Wood	— Corral	—	—	—	—	—	—	—	—	
	FALL	2.50 Wood	L/S Corral	2.50 / 2.56	W/S	2.59 W/S	W/C *	3.75 P	—	—	—	
PIPES ABANDONED OR IN POOR CONDITION	SPRING +F.P.	—	—	—	—	—	—	—	—	—	—	
	SPRING -F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL +F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL -F.P.	—	—	—	—	—	—	—	—	—	—	
EROSION ON BANK OR SLOPE	SPRING	0.06 / 0.04 W/S	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
TRIM TREES	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	2.51 / 0.52	2.67 / 2.68	—	—	—	—	—	—	—	—	
	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	

REMARKS SPRING: ~~Spray or remove the wild growth from the levee slopes and/or the rock revetment. *Investigate encroachment~~

REMARKS FALL: Spray or remove the wild growth from the levee slopes and/or the rock revetment. *Investigate encroachment. Both slopes were burned where practical.

INSPECTED BY ~~A. Voorsen~~ APPROVED BY [signature] DATE 1/23/86

REVIEWED AND COPY RECEIVED BY [signature] DATE 1-23-86

L.S. LANDSIDE W.S. WATERSIDE +F.P. ABOVE FLOOD PLANE -F.P. BELOW FLOOD PLANE

ENCROACHMENT SYMBOLS:

A - SIGNS C - LANDSCAPING E - EQUIPMENT OR MATERIAL G - GARBAGE OR TRASH T - TANK

B - BUILDINGS D - STAIRWAYS F - FENCES H - POLES P - PLUMBING

DWR 167 (REV 7/68)

District or Area ~~Yolo Co. S.A. #6~~

FLOOD CONTROL PROJECT MAINTENANCE

LEVEE INSPECTION

DISTRICT OR AREA R.D. No. 1500 DATE OF INSPECTION: SPRING 4/1/86 FALL 10/17/85

UNIT NO. 1 LENGTH 33.58 MILES LEVEE L.B. Sacramento River SHEET ___ OF ___ SHEETS

ITEM	IN-SPECTION	MAINTENANCE AND/OR REPAIRS ARE REQUIRED AT THE FOLLOWING LEVEE MILES (FROM) (TO)										TOTAL
CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	32.74 32.75		Berrys								[illegible]
	SPRING W.S.	2.56 2.57	3.32 3.33	Berrys								[illegible]
	FALL L.S.	32.74 32.75										0.01
	FALL W.S.	2.56 2.57	3.32 [illegible]									0.02
(CONT.) CONTROL WILD GROWTH ON LEVEE	SPRING L.S.											
	SPRING W.S.											
	FALL L.S.											
	FALL W.S.											
CONTROL GROWTH IN ROCK REVETMENT	SPRING 26.52	15.77 15.82	20.83 20.90	22.95 22.96	24.05 24.17	24.88 21.89	25.05 25.06	31.74 31.75	Berrys	& Bamboo		0.13
	FALL	15.77 15.92	20.86 2-/0-	22.95 22/07	24.05 24/-8	24.55 24/90	25.05 25.06	31.74 31.75	Berrys	& Bamboo		0.13
EXTERMINATE RODENTS AND FILL BURROWS	SPRING L.S.	0.21	7.42 7.45	2.27	9.01	21.17	32.75		And			6 Sites
	SPRING W.S.	0.17						Where	Needed			1 Site
	FALL L.S.	0.21	21.17			And						2 Sites
	FALL W.S.	0.47				Where Needed						1 Site
REPAIR CROWN ROADWAY	SPRING											
	FALL											
CONTROL LIVESTOCK PASTURING	SPRING											
	FALL											
REPAIR GATES	SPRING											
	FALL	15.08 Change lock										
UNAUTHORIZED ENCROACHMENTS	SPRING	1.31P 1.34G	1.33E 1.41C	3.16G 3.17	3.60E Tractor	5.11E 5.20	6.52P	7.62P Berm	8.69P Berm	8.83P	8.86P 9.25	Contd.
	FALL	1.31P 1.34G	1.33E 1.41G	3.16G 3.17	3.60E	5.11E 5.20	7.45P Berm	7.62P Berm	8.53P	8.56P [illegible]	8.95P Tree	Contd.
PIPES ABANDONED OR IN POOR CONDITION	SPRING +F.P.											
	SPRING -F.P.	6.27	21.60	25.30								3 Sites
	FALL +F.P.											
	FALL -F.P.											
EROSION ON BANK OR SLOPE	SPRING	Bank 0.16 0.34	W/toe 9.74 9.75	Rock 9.88 9.90	Bank 11.93 11.36	16.56* 16.73	20.55* 20.77	*Proposed USCE rock sites- Unit 13				6 Sites
	FALL	0.96 0.34	16.56 16.73	20.55* 20.77				*Proposed USCE rock sites- Unit 13				[illegible] Sites
UNAUTHORIZED ENCROACHMENTS	SPRING	9.22P Tree	14.32P 14.37E	15.91E 15.97P	19.10E Tractor	26.84E Pipes	28.11P					16 Sites
	FALL	14.32P 14.37E	15.91E 15.97P	21.53E	21.82 E	24.07E	26.84 Tire	33.22 33.25				17 Sites
SLIPS OR SUBSIDENCE ON LANDWARD SLOPE & TOE	SPRING	0.58	0.61 0.62	0.63	0.66	0.68						5 Sites
	FALL	0.58	0.51 0.62	0.63	0.66	0.68						5 Sites

REMARKS	SPRING	~~Spray or remove the wild growth from the levee slopes and/or the rock revetment. Mow or burn the levee slopes during the summer months. Remove the unauthorized encroachments listed above.~~ Debris along the waterward slope and berm should be stacked and burned. Walnut trees (26) still ~~encroached on easement of Mr. Driver's property (L.M. 7.62-7.77)~~
REMARKS	FALL	Remove the unauthorized encroachments listed above. The levee slopes were burned, where practical. The levee slopes were dragged, where practical. Debris along waterward slope and berm should be stacked and burned. Walnut trees (26) still encroach on easement of Mr. Driver's property (L.M. 7.64 - 7.67)

INSPECTED BY R. Quinn/A. Silva APPROVED BY [signature] DATE 4/14/86

REVIEWED AND COPY RECEIVED BY [signature] DATE ______

L.S. LANDSIDE W.S. WATERSIDE +F.P. ABOVE FLOOD PLANE -F.P. BELOW FLOOD PLANE

ENCROACHMENT SYMBOLS:

A - SIGNS C - LANDSCAPING E - EQUIPMENT OR MATERIAL G - GARBAGE OR TRASH T - TANK

B - BUILDINGS D - STAIRWAYS F - FENCES H - POLES P - PRUNINGS

DWR 107 (REV 7/68)

District or Area R.D. No. 1500 - 1

THE RESOURCES AGENCY

FLOOD CONTROL PROJECT MAINTENANCE
LEVEE INSPECTION

DISTRICT OR AREA S.R.W.S.L.D. DATE OF INSPECTION: SPRING [illegible] FALL 11/13/35

UNIT NO. ____ LENGTH [illegible] MILES LEVEE [illegible] Sacramento River SHEET ___ OF ___ SHEETS

ITEM	INSPECTION	MAINTENANCE AND/OR REPAIRS ARE REQUIRED AT THE FOLLOWING LEVEE MILES (FROM) (TO)										TOTAL
CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	[illegible]	[illegible].17	—	—	—	—	—	—	—	—	[illegible]
	SPRING W.S.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cont[illegible]
	FALL L.S.	3.43 / 3.44	3.95 / 3.96	[illegible] / 3.55	15.[illegible] / 15.[illegible]	25.15 / 25.17	34.71 / 34.73	[illegible]	36.21 / 36.26	—	—	.17
	FALL W.S.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.95 / 12.01	12.4[illegible] / [illegible]	12.53 / 12.[illegible]	[illegible]	[illegible]	Cont[illegible]
(CONT.) CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	4.43 / 4.5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.21 / 13.51	[illegible]	26.3[illegible] / 26.[illegible]	27.[illegible] / 27.7[illegible]	41.[illegible] / 41.[illegible]	[illegible]
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	26.21 / 26.27	26.30 / 26.31	26.3[illegible] / 26.44	27.69 / 27.75	34.70 / 34.71	35.43 / 35.49	35.57 / 35.75	36.70 / 36.[illegible]	37.79 / 37.[illegible]	—	[illegible]
CONTROL GROWTH IN ROCK REVETMENT	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
EXTERMINATE RODENTS AND FILL BURROWS	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	41.[illegible]	—	—	—	—	—	—	—	—	—	1 Site
	FALL L.S.	5.00 / 5.03	5.15 / 5.17	9.97	17.[illegible] / 17.[illegible]	18.06 / 18.07	18.09	39.15	40.74	—	—	[illegible] Sites
	FALL W.S.	4.75	—	—	—	—	—	—	—	—	—	1 Site
REPAIR CROWN ROADWAY	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	4.70 [illegible]	—	—	—	—	—	—	—	—	—	1 Site
CONTROL LIVESTOCK PASTURING	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
REPAIR GATES	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
UNAUTHORIZED ENCROACHMENTS	SPRING	[illegible]	[illegible] *	[illegible] *	[illegible]	[illegible]	[illegible] *	[illegible] *	[illegible]	[illegible]	[illegible] *	[illegible]elow
	FALL	[illegible].59 *	2.46* / 2.54*	2.70 / 2.71*	2.93 / 2.99F	3.21 / 3.22*	4.59	5.50 P	[illegible] P	7.12 *	9.03 / [illegible]	Below
UNAUTHORIZED ENCROACHMENTS PIPES ABANDONED OR IN POOR CONDITION	SPRING +FP	14.[illegible] / 14.[illegible]	27.[illegible]	21.7[illegible] / 21.[illegible]	—	—	—	—	—	—	—	13 Sites
	FALL -FP	[illegible].72T / [illegible].74P	10.54 P	11.06 / 11.80P	13.54 *	14.39 *	16.77* / 16.80P	19.[illegible]	19.32 *	22.46 *	22.9[illegible] / [illegible] Pipe	Below II
II	FALL +FP	25.60 P*	25.90 *	25.55 *	27.64 *	27.71 P	27.80 P	27.83 P	30.40 / 30.42E	31.79 * P	32.[illegible] Pipes	Below III
III	FALL -FP	34.52 / 34.70P	34.73 P	35.53 *	35.[illegible] / 36.14P	36.33 / 36.35P	36.63* / **36.6[illegible]	40.45 FAPH	40.73 P	41.20 / 41.35P	41.45 / 41.57P	40 Sites
EROSION ON BANK OR SLOPE	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
(1) TRIM TREES	SPRING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.69 / 4.71	11.[illegible] / 11.[illegible]	Cont'd
	FALL	0.70 / 0.75	0.77 / 0.78	[illegible]	0.99 / 1.0[illegible]	1.05 / 1.05	1.17 / 1.[illegible]	1.41 / 1.5[illegible]	1.5[illegible] / 2.18	4.57 / 4.70	5.97 / [illegible]	Trim 2
(2) TRIM TREES	SPRING	14.[illegible] / 14.[illegible]	19.71 / 19.73	[illegible]	12.[illegible]	—	—	—	—	—	—	14 Sites
	FALL	11.90 / 11.95	12.77 / 12.[illegible]	14.51 / 14.[illegible]	36.40 / 36.50	41.29 / 41.32	—	—	—	—	—	15 Sites

REMARKS — SPRING: Spray or remove the wild growth from the levee slopes and/or the rock revetment. Mow the levee slopes during the summer months. Good maintenance. Trees should be trimmed. *Down tree.

REMARKS — FALL: Use of crane and heavy I beam dresses slope nicely. Prune cuttings should be burned. ***Truck bodies (8) farm equipment APH=Abandoned pumphouse outside *Down trees **Corrugated pipes/tank T-Trailer at toe landside

INSPECTED BY [illegible] APPROVED BY ____ DATE ____

REVIEWED AND COPY RECEIVED BY ____ DATE ____

L.S. LANDSIDE W.S. WATERSIDE +F.P. ABOVE FLOOD PLANE -F.P. BELOW FLOOD PLANE

ENCROACHMENT SYMBOLS:

A – SIGNS C – LANDSCAPING E – EQUIPMENT OR MATERIAL G – GARBAGE OR TRASH T – TANK

B – BUILDINGS D – STAIRWAYS F – FENCES H – POLES P–PRUNINGS

DWR 167 (REV 7/68)

District or Area ____

THE RESOURCES AGENCY

FLOOD CONTROL PROJECT MAINTENANCE
LEVEE INSPECTION

DISTRICT OR AREA Yolo Co. Service [illegible] DATE OF INSPECTION: SPRING [illegible] FALL [illegible]

UNIT NO. ____ LENGTH [illegible] MILES LEVEE [illegible] Sacramento River SHEET ___ OF ___ SHEETS

ITEM	IN-SPECTION	MAINTENANCE AND/OR REPAIRS ARE REQUIRED AT THE FOLLOWING LEVEE MILES (FROM)/(TO)										TOTAL
CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	[illegible] / 2.11	2.21 / [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—	[illegible]
	SPRING W.S.	1.23 / 1.25	2.01	2.11 / [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	—	0.13
(CONT.) CONTROL WILD GROWTH ON LEVEE	SPRING L.S.	—	—	—	—	—	—	—	—	—	—	
	SPRING W.S.	—	—	—	—	—	—	—	—	—	—	
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	—	—	—	—	—	—	—	—	—	—	
CONTROL GROWTH IN ROCK REVETMENT	SPRING	[illegible]	[illegible]	3.34 / 3.45	—	—	—	—	—	—	—	[illegible]
	FALL	2.35 / 2.55	2.38 / 2.55	3.34 / 3.45	—	—	—	—	—	—	—	0.30
EXTERMINATE RODENTS AND FILL BURROWS	SPRING L.S.	[illegible]	[illegible]	[illegible]	—	—	—	—	—	—	—	3 Sites
	SPRING W.S.	—	—	—	—	—	—	—	—	—	—	
	FALL L.S.	—	—	—	—	—	—	—	—	—	—	
	FALL W.S.	—	—	—	—	—	—	—	—	—	—	
REPAIR CROWN ROADWAY	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
CONTROL LIVESTOCK PASTURING	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
REPAIR GATES	SPRING	—	—	—	—	—	—	—	—	—	—	
	FALL	—	—	—	—	—	—	—	—	—	—	
UNAUTHORIZED ENCROACHMENTS	SPRING	[illegible]	1.19 *	[illegible] *	[illegible] *	[illegible]	[illegible] **	[illegible] **	[illegible]	[illegible] *	[illegible] Stump	Contd. [illegible]
	FALL	0.45 / [illegible]	0.63G / 0.65	1.25 *	1.29 *	4.01 A-Car	—	—	—	—	—	5 Sites
PIPES ABANDONED OR IN POOR CONDITION	SPRING +F.P.	—	—	—	—	—	—	—	—	—	—	
	SPRING -F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL +F.P.	—	—	—	—	—	—	—	—	—	—	
	FALL -F.P.	—	—	—	—	—	—	—	—	—	—	
EROSION ON BANK OR SLOPE	SPRING	2.25	—	—	—	—	—	—	—	—	—	1 Site
	FALL	—	—	—	—	—	—	—	—	—	—	
TRIM TREES	SPRING	[illegible]	1.00 / 1.13	[illegible]	2.65 / [illegible]	—	—	—	—	—	—	4 Sites
	FALL	0.02 / 0.04	0.15 / 0.16	0.96 / 0.98	1.00 / 1.13	—	—	—	—	—	—	4 Sites
UNAUTHORIZED ENCROACHMENTS	SPRING	4.01 Abandon car	—	—	—	—	—	—	—	—	—	11 Sites
	FALL	—	—	—	—	—	—	—	—	—	—	

REMARKS SPRING: **Corrals made of wooden pallets.
*Down tree

REMARKS FALL: Landward side slopes look good. Spray waterward side growth.

INSPECTED BY A. Vasquez APPROVED BY [signature] DATE [illegible]

REVIEWED AND COPY RECEIVED BY [signature] DATE 12/10/86

L.S. LANDSIDE W.S. WATERSIDE +F.P. ABOVE FLOOD PLANE -F.P. BELOW FLOOD PLANE

ENCROACHMENT SYMBOLS:

A - SIGNS C - LANDSCAPING E - EQUIPMENT OR MATERIAL G - GARBAGE OR TRASH T - TANK

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DWR 187 (REV 7/86)

District or Area Yolo County S.A. [illegible]

APPENDIX D: AERIAL PHOTOGRAPHY COVERAGE

Preflood Coverage

17-20 March 1984

23 9- by 9-in. frames @ $7.40	$170.20
12 24- by 24-in. frames @ $28.00	$336.00

This coverage was obtained from the Western Aerial Contractors (WAC) Corporation. The 9- by 9-in. 1:31,680-scale black-and-white prints were purchased in stereo. Enlargements were not purchased in stereo pairs. The resolution and quality of these photos was very good. Vegetation could easily be seen, and river stages were low enough to allow revetments to be visible.

The enlargements were used as the primary source of information on preflood revetment vegetation. All vegetation identified in the enlarged photos was verified in stereo using the smaller prints. In some locations where the perspective was poor or shadows were present, stereo interpretation was the only means of positive identification. Using physical enlarged coverage along with stereo coverage at the original scale is a cost-effective technique, provided the scale of the photos is not too small.

22 May 1984

9- by 9-in. frames @ $5.00	$45.00

The original scale of this black-and-white coverage was 1:54,000. These photos were used to produce the 1984 Air Atlas. This coverage was obtained in 9- by 9-in. stereo pairs from the Sacramento District. These photos were seldom used, for several reasons. The resolution was poor, and contrast was slightly darker than normal. There was also a good bit of sunlight reflected from the water over major portions of the river. Out of nine photos, only one had no sun reflection from the river. Although riverbanks were visible, the reflection from the water made stereo viewing difficult. When viewed in stereo, often only one frame would have an area obscured by glare. This was very distracting. The scale of these photos was too small to use to identify revetment vegetation.

June 1984

These National High Altitude Program color infrared photos were purchased in 9- by 9-in. 1:58,000-scale prints and 38- by 38-in. enlargements.

The resolution, contrast, and quality were very good. There was no specular reflectance, and river stages were normal to low. Although the scale was small, the 9- by 9-in. prints provided good stereo viewing. Photos were placed on a light table that was used to spot check areas that were difficult to interpret due to shadows, etc.

The enlargements were also viewed in stereo but with some difficulty. The 38- by 38-in. prints were too large to be viewed through a table-top stereoscope. Stereo viewing was accomplished by moving two tables together so that a small space (approximately 1 in.) between the tables was centered under the stereoscope. The photos were then maneuvered so that the desired area could be brought into view, allowing the prints to hang into the space between tables. This method was a bit cumbersome at first but proved to be very effective and caused no damage to the prints.

5 38- by 38-in. frames	@ $65.00	$325.00
6 9- by 9-in. frames	@ $24.00	$144.00

Postflood Coverage

4 November 1986

25 9- by 9-in. frames	@ $5.00	$125.00
12 enlargements	@ $20-50.00	

This black-and-white coverage was originally obtained by the DWR for the 1986 Air Atlas. The resolution of the 1:24,000-scale 9- by 9-in. photos was good, but the tones were a little too dark when viewed in stereo. This problem was overcome by placing the photos and the stereoscope on a light table. Using this method, vegetation, revetment damage, and other features could be seen clearly. River stages at the time these photos were taken appeared to be normal, and most revetments were clearly visible. Shadows were minimal since the photos were taken at 11:39 a.m. However, shadows that were present were helpful in identifying vegetation size.

The 1:4,800-scale enlargements were also used, but not in stereo. The enlargements were much lighter than the smaller imagery, and the resolution was very good. The scale of these enlargements was approximately equal to the scale of the 1986 Air Atlas blue-line sheets and acetate overlays. Although there was some random distortion between photos as a result of the enlargement process, these photos were invaluable for determining the exact type and location of bank line features.

Hand-held camera color prints taken on the ground were used in combination with the enlargements to identify vegetation size and type. Landmarks such as power lines, orchards, and other structures seen in the snapshots were first located on the enlarged photos. Once the location was confirmed, vegetation types could easily be identified on the enlargements and in the smaller stereo imagery.

The enlargements varied in size, with the maximum size estimated as 48 by 48 in. The estimated cost per print ranged from $20.00 to $50.00.

Spring 1987

13 38- by 38-frames @ $65.00	$845.00
7 9- by 9-in. frames @ $24.00	$168.00

This National Aerial Photography Program color infrared coverage was purchased in 9- by 9-in. 1:40,000-scale prints and 38- by 38-in. enlargements. Both sizes were purchased in stereo. The quality of these photos was very good. They were used primarily to verify the features seen in the 1986 Air Atlas enlargements. The river stages were low enough to reveal revetments and vegetation. Although the quality and scale of these photos was good, four of the seven frames had sections approximately 2 river miles in length obscured by specular reflectance. As stated above, this made stereo viewing difficult. The 38- by 38-in. enlargements were viewed in stereo in the same manner as the 1984 color IR coverage described above.

March, July, September 1985

21 20- by 20-in. frames @ $45.00	$945.00

This 1:62,000-scale coverage was purchased from the EROS Data Center. The quality of these NASA color infrared photos was very good. Although the scale was a bit small, the resolution was exceptional. The frames were small enough to be easily handled under the stereoscope. There was a slight dark tint in the photos which was overcome by using a light table. Revetment features and vegetation showed up very clearly in the photos. They were used primarily to verify the information taken from the 1986 Air Atlas photos. The only inconvenience associated with these photos was that there was no date or

scale printed on the borders. Numbers such as time of day, frame number, and roll number were printed on the two sides of each frame, which made it difficult to determine the direction of flight. Extra time was spent looking up the photo scale and date information in other documents.

APPENDIX E: PORTION OF DATA BASE REPRESENTING 1986 CONDITONS

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	RIVER	DISTANCE	REVET/MI	YEAR	MATERIAL	85 INSP	86 INSP	DAM/WET	DAM/PL99	PREVEG	POSTVEG	PLANFORM	1=L 2=R
2	MILE	(FT)											
3					0=No Rev	0=No Veg	0=No Veg	0=No Dam	0=No Dam	1=No Veg	1=No Veg	1=Straight	
4					1=Cobble	1=Veg	1=Veg	1=Damage	1=Damage	2=Shrubs	2=Shrubs	2=In Bend	
5					2=Riprap	-10=RM	-10=RM	-10=RM	-10=RM	3=Trees	3=Trees	3=Out Bend	
6					3=Rubble					-10=RM	-10=RM	4=In P.Bar	
7												5=Out P.Bar	
8													
9	83.5	0			-10	-10	-10	-10	-10	-10	-10	-10	1
10	84.0	2623			-10	-10	-10	-10	-10	-10	-10	-10	1
11		4883	84.5	1979	2	0	0	0	0	3	2	1	1
12		4983	84.5	1979	2	0	0	0	0	3	2	1	1
13		5083	84.5	1979	2	0	0	0	0	3	2	1	1
14	84.5	5183	84.5	1979	2	0	0	0	0	1	1	1	1
15		5283	84.5	1979	2	0	0	0	0	1	1	1	1
16		5383	84.5	1979	2	0	0	0	0	1	1	1	1
17		5483	84.5	1979	2	0	0	0	0	1	1	1	1
18		5583	84.5	1979	2	0	0	0	0	1	1	1	1
19		5683	84.5	1979	1	0	0	0	1	1	1	5	1
20		5783	84.5	1979	1	0	0	0	1	1	1	5	1
21		5883	84.5	1979	1	0	0	0	1	1	1	5	1
22		5938		1945	1	0	0	0	1	1	1	5	1
23		6038		1945	1	0	0	0	1	1	1	5	1
24		6138		1945	1	0	0	0	1	1	1	4	1
25		6238		1945	1	0	0	0	1	1	1	4	1
26		6338		1945	1	0	0	1	1	1	1	4	1
27		6438		1945	1	0	0	1	1	1	1	4	1
28		6538		1945	1	0	0	1	1	1	1	4	1
29		6638		1945	1	0	0	1	1	1	1	4	1
30		6738		1945	1	0	0	1	1	1	1	4	1
31		6838		1945	1	0	0	1	1	1	1	3	1
32		6938		1945	1	0	0	1	1	1	1	3	1
33		7038		1945	1	0	0	1	1	1	1	3	1
34		7138		1945	1	0	0	1	1	1	1	3	1
35		7238		1945	1	0	0	0	1	1	1	3	1
36		7338		1945	1	0	0	0	1	1	1	3	1
37		7438		1945	1	0	0	0	1	1	1	3	1
38		7538		1945	1	0	0	0	1	1	1	2	1
39		7638		1945	1	0	0	0	1	1	1	2	1
40		7738		1945	1	0	0	0	1	1	1	2	1
41		7838		1945	1	0	0	0	1	1	1	2	1
42	85.0	7938		1945	1	0	0	0	1	1	1	2	1
43		8038		1945	1	0	0	0	1	1	1	2	1
44		8128	85.1	1979	2	0	0	0	1	1	1	2	1
45		8228	85.1	1979	2	0	0	0	1	1	1	5	1
46		8328	85.1	1979	2	0	0	0	1	1	1	5	1
47		8428	85.1	1979	2	0	0	0	1	1	1	5	1
48		8528	85.1	1979	2	0	0	0	1	1	1	5	1
49		8628	85.1	1979	2	0	0	0	1	1	1	5	1
50		8728	85.1	1979	2	0	0	0	1	1	1	5	1
51		8828	85.1	1979	2	0	0	0	1	1	1	5	1
52		8928	85.1	1979	2	0	0	0	1	1	1	5	1
53		9028	85.1	1979	2	0	0	0	1	1	1	5	1
54		9128	85.1	1979	2	0	0	0	1	1	1	5	1
55		9228	85.1	1979	2	0	0	0	1	1	1	4	1
56		9328	85.1	1979	2	0	0	0	1	1	1	4	1
57		9397	85.5	1973	2	0	0	0	1	1	1	4	1
58		9497	85.5	1973	2	0	0	0	0	1	1	4	1
59		9597	85.5	1973	2	0	0	0	0	1	1	4	1
60		9697	85.5	1973	2	0	0	0	0	1	1	1	1
61		9797	85.5	1973	2	0	0	0	0	1	1	1	1
62		9897	85.5	1973	2	0	0	0	0	1	1	1	1
63		9997	85.5	1973	2	0	0	0	0	1	1	1	1